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AXIAL THRUST MEASUREMENT SYSTEM CERTIFICATION FOR PROPULSION DEVELOPMENT TEST CELL J-2

R. B. Runyan
ARO, Inc.

September 1979

Final Report for Period August 1972 through December 1974

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This report has been reviewed and approved.

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FOR THE COMMANDER

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Summary

This report presents the results of investigations and calibrations performed during the certification and initial use of the J-2 force measuring system. The system accuracy and operating characteristics were determined and are presented. Specific potential problem areas were identified and investigated and the results are shown. It was determined that the force measuring systems is capable of meeting force measurement needs resulting from present and projected test article performance requirements.

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1.0 INSTRODUCTION

The force measuring system for the Propulsion Engine Test Cell J-2 (Fig. 1) of the Engine Test Facility was designed to measure axial forces produced by turbojet and turbofan engines up to force levels of 70,000 lb_f. The present installation was optimized to measure axial forces up to 25,000 lb_f. Certification testing of the force measuring system will be a continuing effort during engine testing and modifications to this system will be made as necessary to further improve operation and accuracy.

Several areas were considered as potential problem areas, therefore, specific methods of calibrations were designed and performed to investigate these areas. The primary areas to be considered were:

1. System force measurement uncertainty
2. Pressure and temperature effects on the measurement load cells.
3. Pressure effect on test cell.
4. Effect of off center thrust stand loading
5. Lab seal tare effects
6. Cell cooling airflow effect
7. Temperature effects on thrust stand
8. Thrust stand repeatability, hysteresis and tare
9. Computer thrust calibration and data reduction program

The thrust system calibration results presented in this report were obtained during engine testing and system checks conducted from August 1972 to December 1974. The data presented include overall system accuracy, as well as pressure and various test cell effects on the thrust stand.

The certification was to support testing conducted by AEDC. Under the Sponsorship of the Aeronautical Systems Division (ASD), Air Force Systems Command (AFSC), Wright Patterson Air Force Base, Ohio under Program Element 64215F.

The results were obtained by ARO, Inc., AEDC Division (a Sverdrup Corporation Company), contract operator of the AEDC, Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee. The tests were conducted in Propulsion Development Test Cell J-2 of the Engine Test Facility (ETF) under ARO Project Number RA175, RA299, RA351 and R41K-05A.

2.0 APPARATUS

2.1 Thrust System

The thrust system installed in the J-2 test cell consists of a fixed frame and a floating frame, data and calibrate load trains, calibrator, and calibrator control system. The overall length of the stand is 26 ft 4 in. and it weighs 13,000 lb. The engine and associated hardware increases the weight of the total system to 20,000 lbs in the final configuration. Figure 2 shows the thrust stand installation in the test cell.

2.1.1 Thrust Stand Frames

The floating portion of the stand is of box beam type construction and covered on the outside by 2 inches of insulation. This stand is cooled by water sprayed on the interior surfaces. The floating portion of the stand is connected to ground (test cell wall) at the aft end through the data load cell and by a single universal flexure in tension for vertical support. The forward end is supported by universal flexures in tension to the fixed portion of the stand. Movement of the stand in the horizontal plane perpendicular to the thrust axis is controlled by side flexures at the forward and aft end of the thrust stand. The calibrator systems are part of the floating portion of the stand and are connected to the fixed portion of the thrust stand through flexures and a cone coupling during calibrations. The calibrator system is completely free of the fixed portion of the stand during testing.

The fixed portion of the stand consists primarily of the forward support frame. The forward support frame (Fig. 1) is water cooled and attached to the test cell floor. The aft support and grounding system is attached directly to the top of the test cell wall.

2.1.2 Load Trains

The floating thrust frame is connected to the fixed frame primarily through the data load train. During calibrations the calibrate load trains also provide a connection to the fixed frame. Both load train systems (Fig. 3) incorporate a load cell with universal flexures at each end and are attached to the frames by couplings. The data load train located at the aft end of the thrust stand is permanently attached to both the floating and fixed frames. The thrust calibrate load train is located at the forward section of the thrust stand and mechanically connected to the test cell only during thrust stand calibration. The drag calibrate load train is located at the aft section of the thrust stand, but forward of the data load train. This load train is physically located inside the floating box beam structure. The connection to the fixed frame is provided through flexures on parallel pull rods along the side of the aft end of the stand when the drag calibrator is being used.

2.1.3 Calibrators

A screw jack driven by an electric motor in both the thrust and drag calibrator mechanisms (Fig. 3) applies forces to the system through a series of levers and pull rods. The thrust calibrator load cell is loaded in tension which loads the data load cell in tension and corresponds to the direction of a positive engine thrust load. The drag calibrator load cell is loaded in tension which loads the data load cell in compression and corresponds to the direction of an engine drag load.

The calibration system has the capability of inplace calibrating the data load train using a working standard calibrator load cell. The calibrations are performed automatically in the thrust and drag directions during normal pre and post test calibrations. The system also has the capability of performing 1) a force load calibration check at any load level or cell pressure level with the engine off and 2) a tare slope check by applying a one point null load while the engine is operating.

2.1.4 Calibrator Control

An electronic system located in the J-2 control room energizes and de-energizes the calibrator to provide the automatic calibration feature of the calibration system. Upon actuation of this system, the data load cell in the thrust stand is calibrated from the no-load or null position to full load in the drag direction (-10,000 lbs compression) to null, to full-load in the thrust direction (20,000 lbs tension), and back to null. After completion of the calibrate cycle, the calibrator is deactivated. The time required for a complete calibration cycle is approximately 4 minutes. In addition to the automatic slow sweep calibration, the calibrator control can be used to set and hold known tension or compression loads on the thrust systems. The maximum force and drag calibrate levels are variable and can be adjusted to desired levels with meter readouts.

2.1.5 Engine Centerline Force Application

Thrust system checks were made by applying forces at the engine centerline location with a simulation of the engine weight installed. The forces were applied using a hydraulic force unit and were set at predetermined levels from 0 to 25,000 lbs in the thrust direction. This calibration was performed twice, once using a working standard from the ARO Technical Services Division (TSD) standards laboratory and once using the J-2 calibrator load cell to measure the applied forces.

2.2 Test Cell

The Propulsion Development Test Cell (J-2)(Fig. 1) is water-cooled and has a 20-ft-diameter by 69-ft-long test section. The 180-deg clam shell hatch is 35 ft, 4 in. in length and opens 30 deg beyond the cell vertical centerline to allow for easy entry of the test article. Additional information on the test cell can be found in the Test Facilities Handbook.*

2.3 Installation

The general arrangement of the engine and thrust stand installed in the J-2 test cell is shown in Fig. 1. The engine was attached to the floating frame of the thrust stand with a box beam structure so that the engine centerline was approximately 9 ft below the thrust stand centerline. An additional structure was located forward of the box beam structure to carry the weight of the inlet ducting directly to the floating stand. The stand was isolated from the fixed inlet ducting by a labyrinth (lab) seal in the engine inlet ducting.

The lines attached to the engine and the floating frame, such as fuel lines, starter air line, and stand water-cooling line were brought in at right angles to the direction of axial movement. The starter air line was a flexible line and the fuel line was a hard line (Fig. 4a). The pneumatic pressure lines are hard lines to a disconnect panel (Fig. 4b) attached to the floating portion of the stand. The hard lines provided better repeatability of tare loads even though they produced a higher tare load than flexible lines would.

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*Test Facilities Handbook (Eleventh Edition). "Engine Test Facility, Vol. 2." Arnold Engineering Development Center, June 1979.

An automatically pressure-balanced labyrinth seal (Fig. 4c) was used between the engine inlet ducting and the engine inlet bellmouth. The bellmouth is attached to the test cell inlet air ducting. With this type seal, no additional tare forces are introduced between the engine inlet duct and the test cell ducting. The normal mode of operation is to have BP-1 (Fig. 4d) set equal to the average of the lab seal wall static pressures which would result in a no flow balance condition. Specific test conditions such as sea level static would require PB-4 to be balanced against cell pressure and lab seal air flow to maintain this balance would flow into the engine inlet duct and would be measured by an orifice in the lab seal airflow supply line.

2.4 Instrumentation

Instrumentation was required to measure force, pressure, stand deflection and thrust stand and load cell temperatures. Instrumentation locations were as shown in Fig. 5.

The force measuring system utilized three dual bridge strain gage-type load cells. The data load cell was a 20,000 lb load cell and was inplace calibrated for each test period. The thrust and drag calibrate load cells were 20,000 lb load cells and were working standard load cells which were periodically calibrated against a secondary standard by the TSD standards laboratory. The standards are directly traceable to NBS.

Pressure measurements were made with strain gage type pressure transducers which were inplace calibrated with a precision quartz pressure gage instrument. Temperatures were measured with thermocouples which were calibrated by millivolt substitution, pre and posttest. Thrust stand deflections were measured by 0- to 0.1-in. precision-dial indicators. These indicators are accurate to the nearest 0.001 in. and are checked periodically.

2.5 Data Conditioning and Recording

Force, pressure and temperature data were recorded on a high speed digital data acquisition system (DDAS). The system digitizes at a 20,000 samples per second rate. Normal channel sample rate is 100 samples per second per channel. Pressures were recorded through the scanner valves which were controlled by the DDAS. Temperatures were routed to either continuous recording channels or to low speed multiplexers for sampling.

All DDAS data were recorded on magnetic tape and were either routed, on-line, to the data reduction computer for processing and printout or were processed off-line at a later time.

Thrust system calibrations were recorded and processed in this manner and were controlled by the thrust system calibrator located in the control room. Thrust calibrations are made automatically by loading the thrust system continuously first in the drag direction, then to null, loading in the thrust direction, then to null while automatically recording the outputs of the calibrate and data load cells with the DDAS.

3.0 PROCEDURE

3.1 Thrust System Calibrations

Prior to and following each engine test period, automatic thrust system calibrations were obtained using the J-2 thrust system calibrator. During these calibrations the test cell was at ambient pressure conditions and the engine was not operating. The cell and thrust stand cooling water was turned on several hours before calibration to allow cell wall and thrust stand temperatures to stabilize.

3.2 Tare and Deflection Checks

A tare load was calculated at each force level during the inplace calibration. This tare load was not used in the processing of the engine scale force measurements, but was used only for analysis of the stand and data processing system. During the buildup and installation phase in J-2 test cell this tare measurement was used to check the installation of each major component such as the fuel line and the lab seal systems. This monitoring helped determine the amount of tare and its repeatability for each system as it was installed. The deflection versus load applied was determined after the installation of all of the major components was completed (Fig. 6). The deflection was measured at the aft end of the thrust stand to determine the movement of the stand in relation to the stand wall.

3.3 Thrust Stand Alignment Checks

Thrust stand optical alignment checks were performed by the TSD standard laboratory during and after installation of the thrust stand. The optical alignment utilized points on each of the two flexures in each load train and reference points on the test cell. Checks were made in both the horizontal and vertical reference plane at each point.

3.4 Engine Centerline Force Application

The engine centerline force application test was conducted without the engine installed. A tank was installed and filled with water to simulate the engine weight, and force was applied in the thrust direction at the engine centerline (Fig. 7). The force level applied was determined with the calibrate load cell located on the engine centerline. The force transmitted through the thrust stand was measured with the data load cell and the DDAS. These forces were compared to the load transmitted through the force system with equivalent loads applied in the normal calibrate position. The loads were applied in 5,000 lb_f increments from 0 to 20,000 lbs.

3.5 Pressure Calibrations

Pressure effects on the load cells were determined by the TSD laboratory by varying the load cell ambient pressure and measuring the equivalent force output.

The effects of pressure on the test cell and the thrust stand were obtained with the thrust stand in the no-load or null position and the engine installed, but not operating. The test cell was evacuated to a particular pressure level and thrust system data were obtained. Data were obtained at several pressure levels during several air periods.

3.6 Data Acquisition and Reduction

3.6.1 Automatic Calibration

The thrust system was automatically calibrated in approximately 4 minutes. During the slow sweep traverse of the thrust system, one record of data was obtained every 2.5 sec. This record consists of 10 samples of each thrust channel and averaged over a time interval of 0.2 sec. The six channels of thrust data were sampled consecutively and the time to acquire one sample of all 6 data channels was 3×10^{-4} seconds. During the thrust portion of the calibration in which the load is applied from 0 to 20,000 lbf and back to 0, approximately 35 of these data records are obtained. Each record averages a load change of approximately 120 lb_f. These records are fit with a least-squares, second-order curve with separate curves for each calibrate load cell bridge in both the tension and compression directions. The data are processed so that the average of the calibrate load cell bridges are curve fit against each of the two bridges of the data load cell bridges.

A format of the thrust system data obtained during a calibration is shown in Appendix A. An explanation of each column is included. During each calibration, curve fit deviation of tare load and zero levels were obtained so that any changes from previous calibrations were immediately evident.

3.6.2 Steady-State Data Points

During a typical steady-state data point, force data were obtained at the same interval as pressure data. Pressure and force data were obtained at each of ten scanner valve positions that together constituted a steady-state data point and covered a time interval of approximately 90 sec. Data obtained at each valve position consisted of three records covering a time interval of five seconds. Two of the three records consisted of ten samples of the thrust data and the other record contained nine samples. Each of the records covers a time interval of 0.2 sec. Therefore, each data point consisted of 290 samples of each channel of thrust data, which are averaged for a value of thrust.

The six thrust values obtained from four calibrate load cell bridges and two data load cell bridges were printed out for each data point. This printout allowed the calibrate load cells to be monitored during testing to insure that no load was inadvertently being applied with the calibrate system. This system also allowed for direct comparison of a calibrate load with a data cell load at a particular level with the engine not operating.

4.0 RESULTS AND DISCUSSION

Certification test data of the J-2 thrust system defining the operating characteristics of the system were obtained prior to and during the engine testing. The system uncertainty, repeatability, hysteresis and tare loads were defined. Necessary adjustments to measured force data were determined and formulated. Continual verification of these adjustments are accomplished during testing by various thrust system checks.

4.1 Thrust Systems Uncertainty

The uncertainty in thrust system measurement was calculated using procedures as outlined in AEDC TR-73-5* and CPIA No. 180** as applicable. The data were obtained during system certification checks and while conducting engine testing. Table I presents the uncertainty values in the form of bias (b) and the precision index (ts) at the 95 percent confidence level. The uncertainty varies from 19 to 33 lb_f over the force range of 0 to 20,000 lb_f.

The uncertainty analysis was accomplished by evaluating various components of the thrust system and combining the errors obtained for each. The specific areas considered were:

1) Laboratory standard
2) Calibrate load cell
3) Thrust system repeatability
4) Data load cell characteristics

4.2 Thrust System Characteristics

4.2.1 Laboratory Calibrations

The load cells were periodically calibrated at the TSD standards laboratory to maintain current records on the loadcell characteristics. The results of a typical calibration are presented in Fig. 8, which shows millivolts for applied load, maximum non-linearity, maximum hysteresis, non-repeatability and equivalent load for resistance cals. The load cell and TSD calibration system repeatability over several calibrations is shown in Figure 9 a, b, and c for the data load cell, thrust calibrate and drag calibrate load cells, respectively. The precision of these data at a 95 percent confidence level is 3.5 lbs over the range of from 0 to 25,000 lbs indicating that the load cells are very repeatable from calibration to calibration. Typical load cell non-linearity characteristics are shown in Figure 10 (a thru c) for all three load cells. The nonlinearity was repeatable and due primarily to the hysteresis in the load cells. The hysteresis is less than 0.02 percent of full scale.

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* Abernathy, R. B., Thompson, J. W., Jr., et al., "Handbook, Uncertainty in Gas Turbine Measurements." AEDC-TR-73-5 (AD755356), January 1973.

** ICRPG Handbook for Estimating the Uncertainty in Measurements Made with Liquid Propellant Rocket Engine Systems. Chemical Propulsion Information Agency, CPIA, No. 180, April 1969.

4.2.1.1 Load Cell Temperature Calibration

The data and calibrate load cells were calibrated at TSD to determine the effect of temperature on the load cell sensitivity (relationship of load applied and millivolt output). Calibrations were performed at several temperatures at load levels of 10,000 and 25,000 lb_f. Deviations in sensitivity from a reference calibration are shown in Figure 11 for two load cells. No trend of variation in sensitivity is evident as a function of load cell temperature. The variation of the load cell zero level as a function of load cell temperature exhibits a definite trend, as shown in Figure 12, for the three load cells used. Since this trend was characteristic of each load cell tested, it should be assumed that any load cell zero level may be sensitive to temperature and should be calibrated for these effects. The zero shift is approximately 0.5 lb per °F, therefore, a requirement was implemented to control the load cell temperature to within ±5°F of the temperature existing at calibration during all engine tests.

4.2.1.2 Off-Axis Loading

A laboratory calibration was performed to evaluate the effect of off-axis loading resulting from having the load cells misaligned. A 10,000 lb_f load was applied with a known axial misalignment of two degrees and the measured output was compared to a reference calibration.

Figure 13 shows the deviation from the reference calibration resulting from the misalignment for three load cells installed in the J-2 thrust stand. The effect for two of the load cells was 15 lb_f and about 35 lb_f for the other load cell which was 0.15 and .35 percent of applied load. These were for a 2° off-axis loading, therefore, the allowable alignment tolerance was set at ±15 minutes of arc for all load cell components.

With the load cell in the off-axis calibration rig the load cell was rotated about its axial centerline and the loading was repeated. The deviation of the loading for the three positions from zero (90°, 180°, 270°) are shown in Figure 13b. The scatter in the data is on the same order of magnitude as any effect of rotation. The maximum effect due to rotation is ~8 lb_f.

4.2.1.3 Adapter Torque

During load cell calibrations, load cell shifts were noticed after installing the adapters. Further investigation revealed that adapter torque effected both the zero level and slope of the load cell output. Because of this effect, a requirement was made that all adapters installed in the J-2 load cells be uniformly torqued to 2000 in.-lbs before laboratory calibration.

4.3 Thrust System Installation Checks

System checks were performed during the installation of the thrust system to insure that this system would meet test requirements. The system was checked for alignment, pressure effects, repeatability and linearity.

4.3.1 System Alignment

Alignment points were provided on the stand hardware during its construction to aid in checking the component alignment after installation. The results of the alignment certification performed by the TSD standards lab is shown in Figure 14. The largest deviation from the centerline is 0.071 inches which is equivalent to an angle of less than 8 minutes of arc. This deviation was judged to be small enough to be acceptable.

4.3.2 Pressure Effect

The load cells were sealed units and were, therefore, affected by environmental pressure changes. The test cell being 20 ft in diameter must withstand larger compressive forces with ambient pressure on the outside and pressures as low as 2 psia on the inside. Any effects that these large forces have on the scale force measurement in the test cell must be evaluated. The pressure effect on the load cell was determined by a calibration of the load cell in a pressure chamber. The pressure effect as determined from the laboratory calibration was compared to data obtained with the load cell and thrust stand installed in the test cell and the test cell at various pressure altitude conditions. Figure 15 shows this comparison over a pressure range of 0.1 psia to atmospheric conditions. The data from the laboratory calibration and the data obtained from the test cell installation agree within the precision of the data in the pressure range of major interest (3 to 6 psia). This indicates there is no significant force interaction resulting from the pressure-area force acting on the test cell.

4.3.3 Centerline Calibration

The calibration loads applied above the engine centerline prior to each test period are assumed to be the equivalent of a load applied by the engine at its centerline. A calibration was performed to certify that a load applied by the calibration system at a point other than the engine centerline is equivalent to an engine applied load (Fig. 7). Tare loads are compared from these calibrations to provide this certification. The difference in the force applied by the calibration system and the force measured by the data load cell is defined as the tare.

The tare force calculated with the force applied at the standard calibration point and the tare force calculated with the force applied at the engine centerline is shown in Figure 16. It is evident from the comparison that there is no discernible effect of applying the force at the calibrate position rather than at the engine centerline. Therefore, the engine applies the same load to the data load cell as the calibrate system.

4.3.4 Labyrinth Seal

The labyrinth seal shown in Figure 4c allows the inlet ducting connected directly to the engine to move freely with respect to the bellmouth ducting. The lab seal is positioned before testing by positioning rods which are remotely controlled to provide a specific radial clearance from the duct. An electric signal is monitored during testing that provides an indication of contact between the lab seal and the inlet ducting. Special test procedures are used to assure that the lab seal is correctly positioned so as to produce no tare effect on the thrust system prior to each test period. In addition, the air used to balance the lab seal is vented radially into the test cell to eliminate any pressure area effect on the system.

4.3.5 Cell Cooling Airflow

Cooling air is supplied to the test cell from either the upstream plenum or atmosphere to provide a positive flow of air through the test cell into the exhaust gas diffuser. The air is supplied by 16 orifices equally spaced around the upstream circumference of the 20' test cell duct. The total cooling airflow is on the order of 20 lb/sec. This flow in the 20 ft diameter test cell produces a velocity that is incapable of producing a significant force on the thrust system.

4.3.6 Temperature Effect on the Thrust Stand

The thrust stand is of box beam type construction that utilizes water sprayed on the internal surface and 2 inches of external insulation for temperature control. The stand is instrumented for temperature effects as shown in Figure 5b and c and the box beam with insulation is shown in Figure 1a. The drag calibrator and thrust data link mechanism are located in areas of the box beam that are protected from the water spray.

The thrust data link is instrumented for temperature as shown in Figure 5c. A nitrogen purge system was provided for the cavity containing the thrust data link (Fig. 3) to aid in temperature control of the data load cell and its linkage. The temperature control of the portion of the linkage from the data load cell that extends beyond the stand box beam to the cell ground is achieved by flowing water through copper tubing wrapped around the linkage.

4.4 Test Results

The data obtained during testing provided information relative to system zero repeatability, calibration repeatability, time shifts, and system precision. The force system was inplace calibrated as part of the pretest and posttest calibration procedure.

4.4.1 Inplace Calibration Repeatability

The thrust system calibration and analysis is described in detail in Appendix A. The calibration results in a second degree curve that relates the reference applied force to the force measured by the data load cell. This relationship must stay constant while testing to ensure accurate force data. Calibrations taken during pretest preparations can be compared to calibrations obtained posttest to measure this repeatability. Data from several calibrations indicate that the calibration system repeats zero within ±10 lb_f and has a precision index of $t_{95} = \pm 9.24$ lb_f. Comparisons of three typical calibrations showing the differences from pre to posttest as a function of applied load is shown in Figure 17.

4.4.2 Data Load Cell Disagreement

The data load cell has two bridges and these outputs are recorded as FA1 and FA2. These are averaged for a value of scale force for each data point. The difference in these two bridges is an indication of the load cell precision and is shown in Figure 18 to be within ±10 lb_f.

4.4.3 Applied Load Test

The J-2 force calibration has the ability of applying a load on the data system at any time. This feature was used to perform an applied load test during several air periods. The applied load test is performed after calibrations are made for an engine test period. A predetermined fixed load is set using the force loading system and a standard data point is recorded and processed with the data system. The data system provides a reading from the data load cell which utilizes the pre-test calibrations. This is compared to the value of the load applied with the loading system, and any differences are noted. These differences are plotted in Figure 19 for several test periods and provide an indication of repeatability of ts = ±25 lb_f at the 95 percent confidence level.

5.0 SUMMARY OF RESULTS

The results of this thrust measurement system certification may be summarized as follows:

1. The force systems uncertainty varies from 19 to 33 lb_f over the force range of 0 to 20,000 lb_f.

2. Thrust stand repeatability was determined to be within ±17 lbs with a hysteresis loop of 15 lbs and a tare load of 75 lbs at a calibration level of 20,000 lbs.

3. The engine applies the same load to the data load cell as the calibrate systems even though the engine is approximately 9' below the centerline of the data load cell.

4. Pressure effects on the test cell were determined to be insignificant.

5. Cell cooling airflow effects were determined to be insignificant.

6. The thrust calibration program provides information on system tare, repeatability linearity and pertinant information on both calibrate load cells and data load cells.

7. The lab seal balance airflow produces no tare effects and the mechanical alignment system eliminates mechanical tare.

8. Thrust stand temperatures can be controlled by water cooling and external insulation for all altitude test conditions.

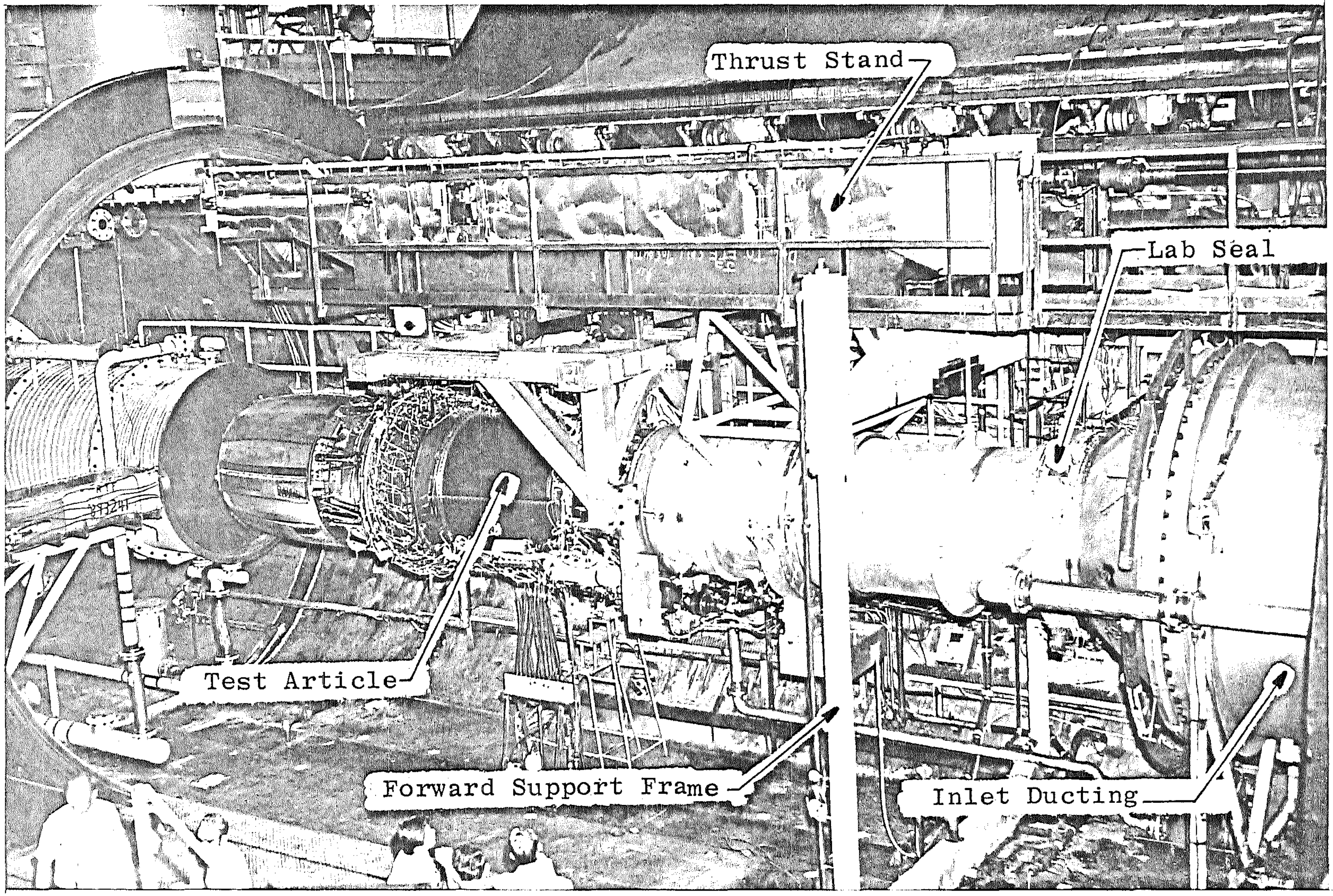
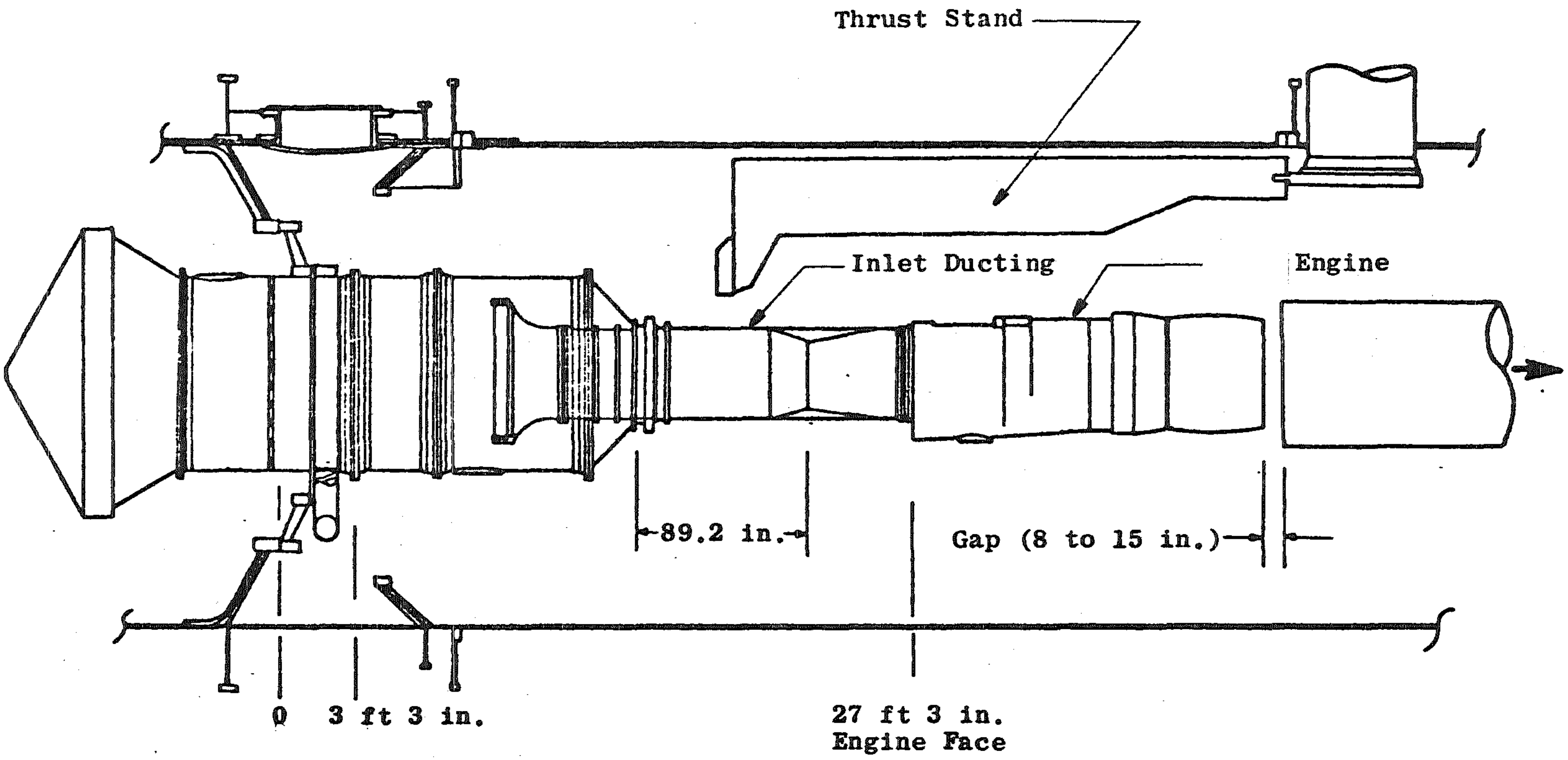
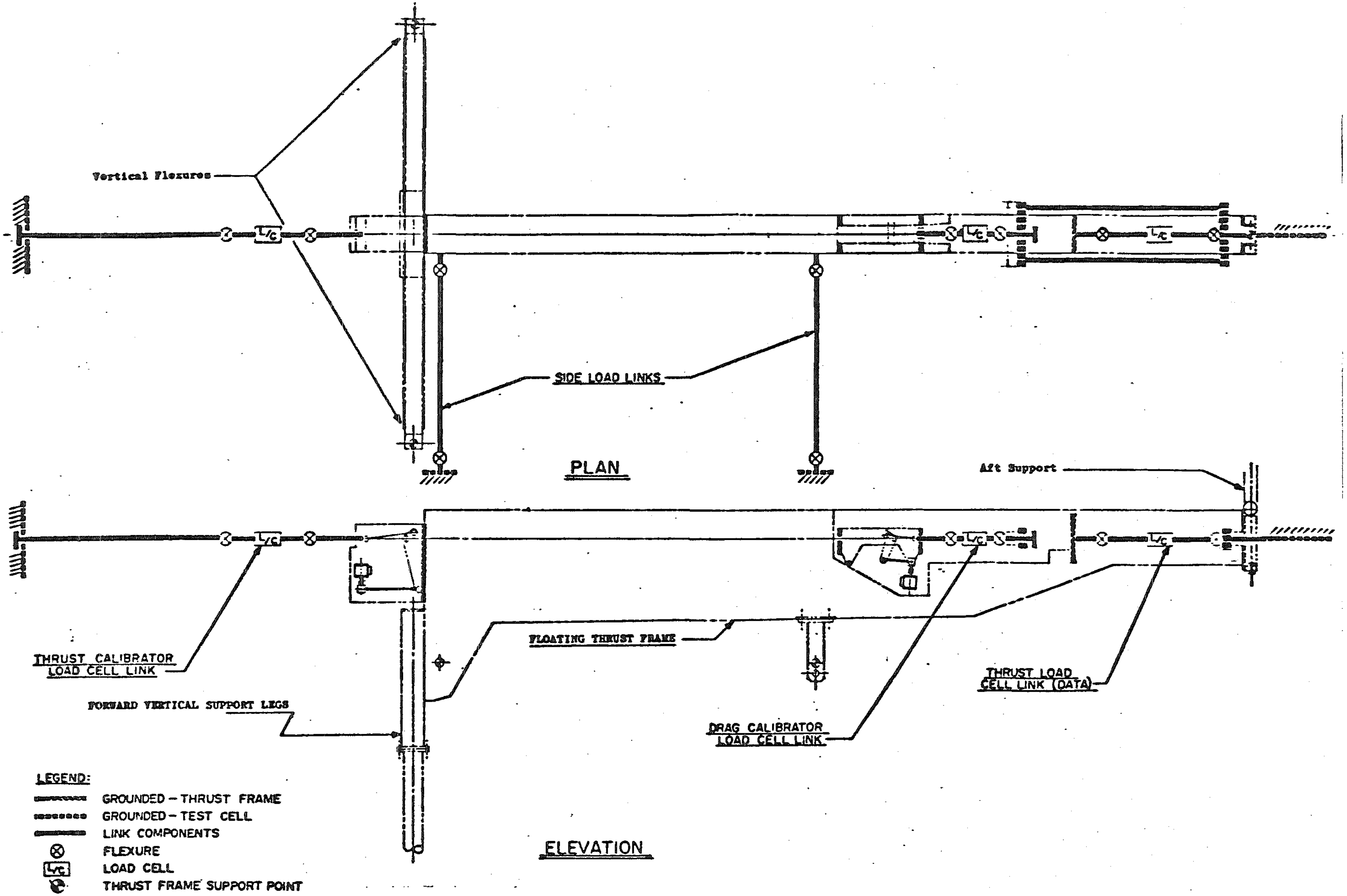


Figure 1. J-2 Test Cell installation view



a. Thrust stand installation layout in Test Cell J-2

Figure 2. J-2 thrust stand



b. Thrust calibration and measurement system

Figure 2. Concluded

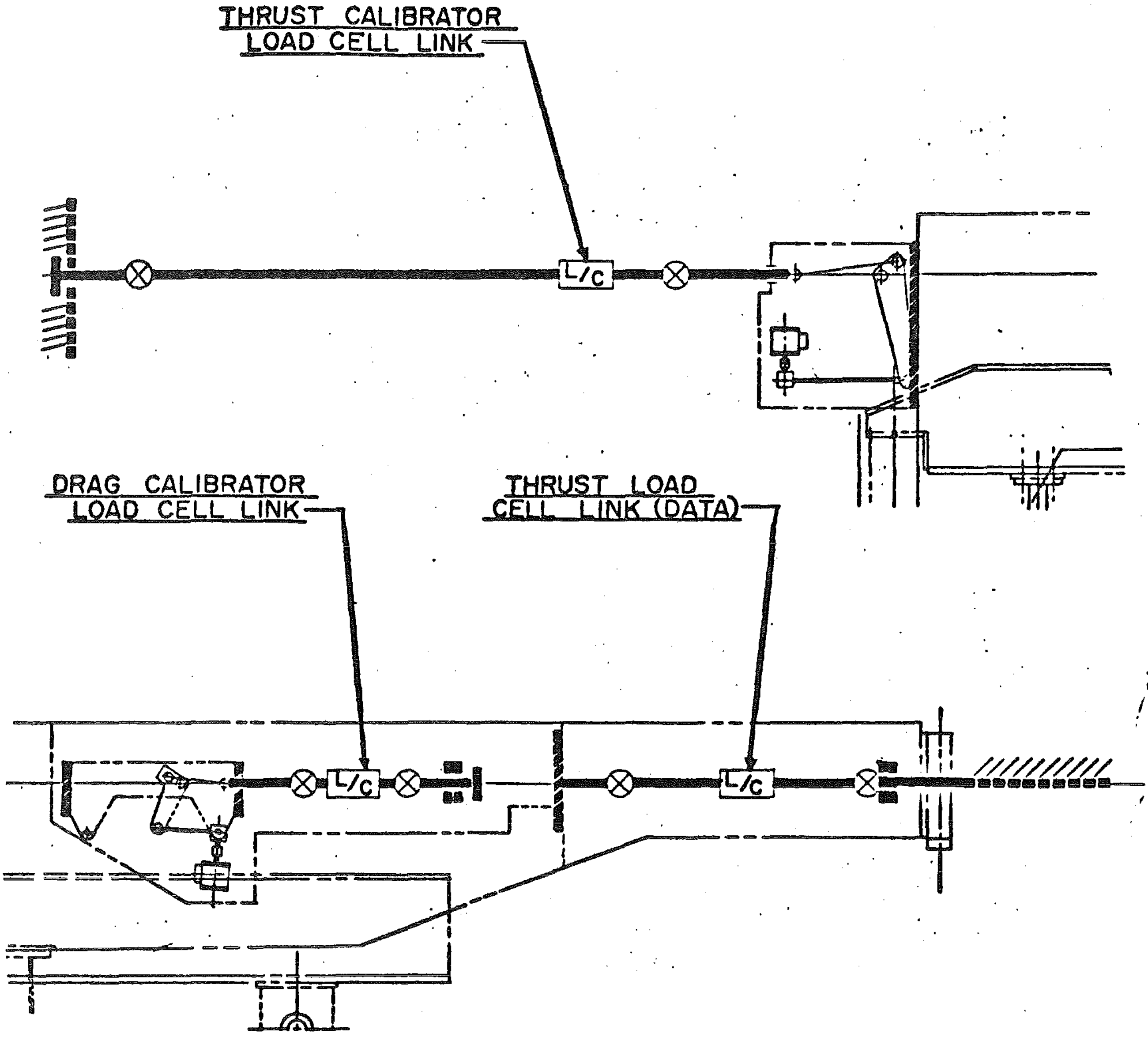
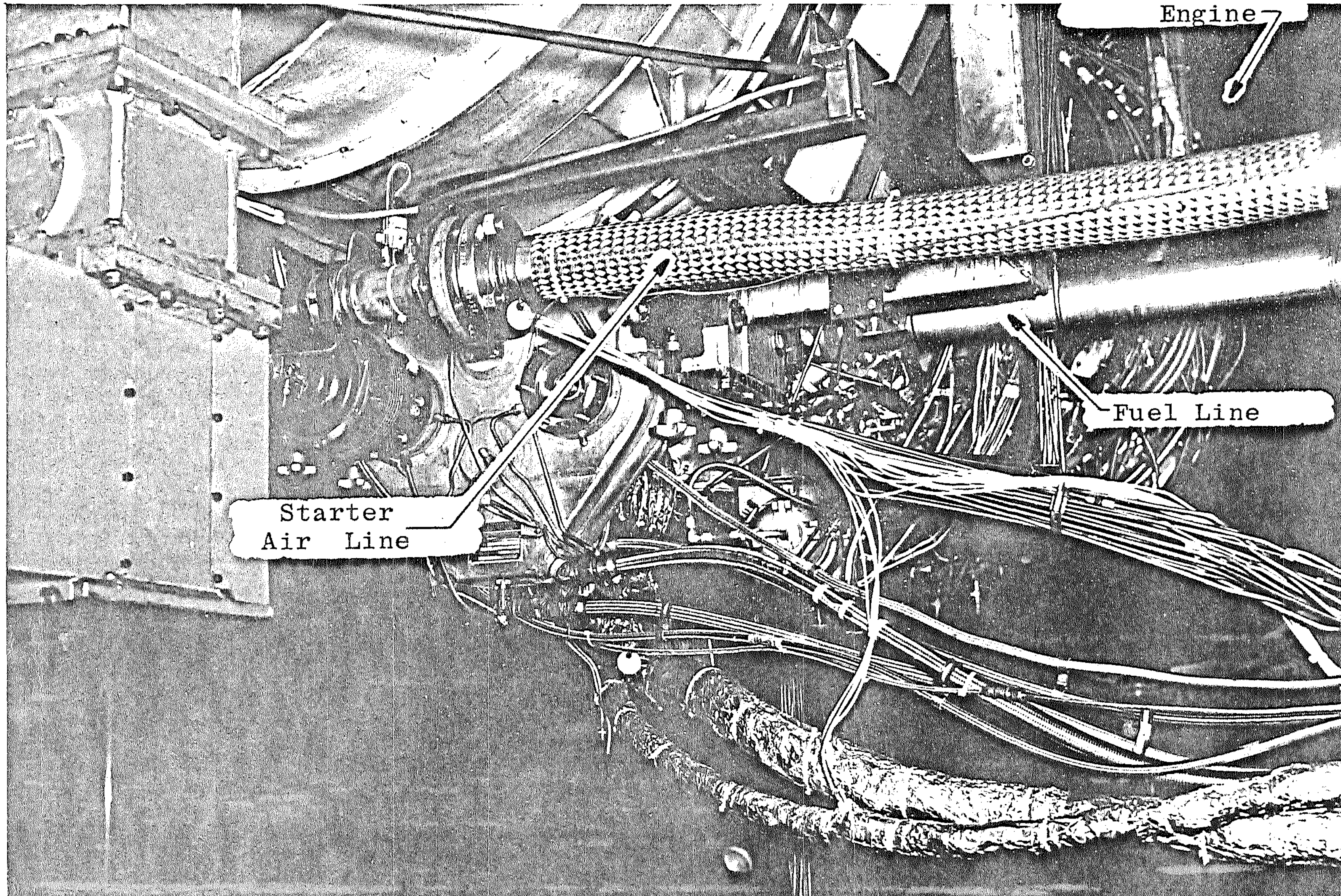
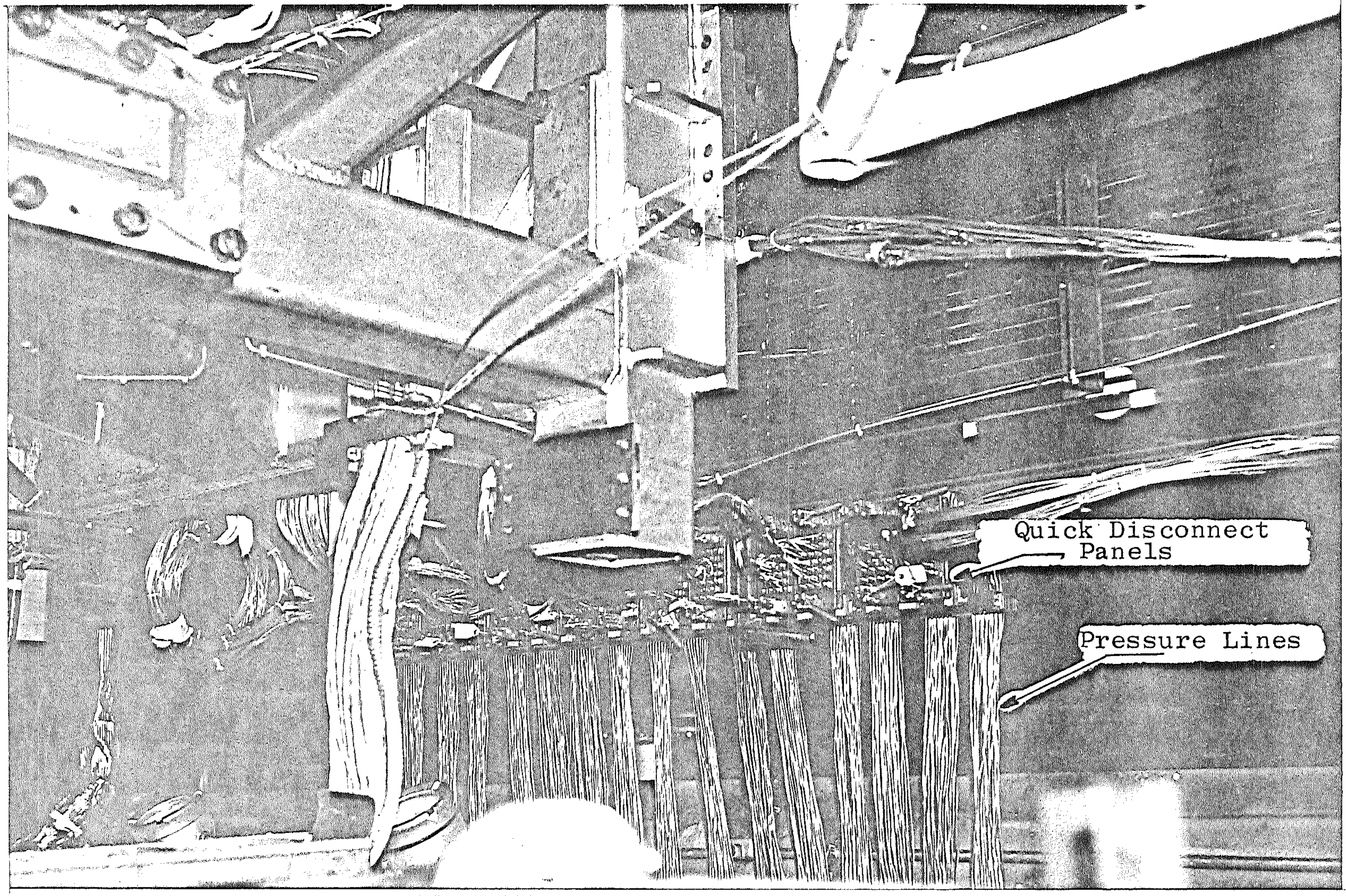


Figure 3. Thrust stand calibration linkage



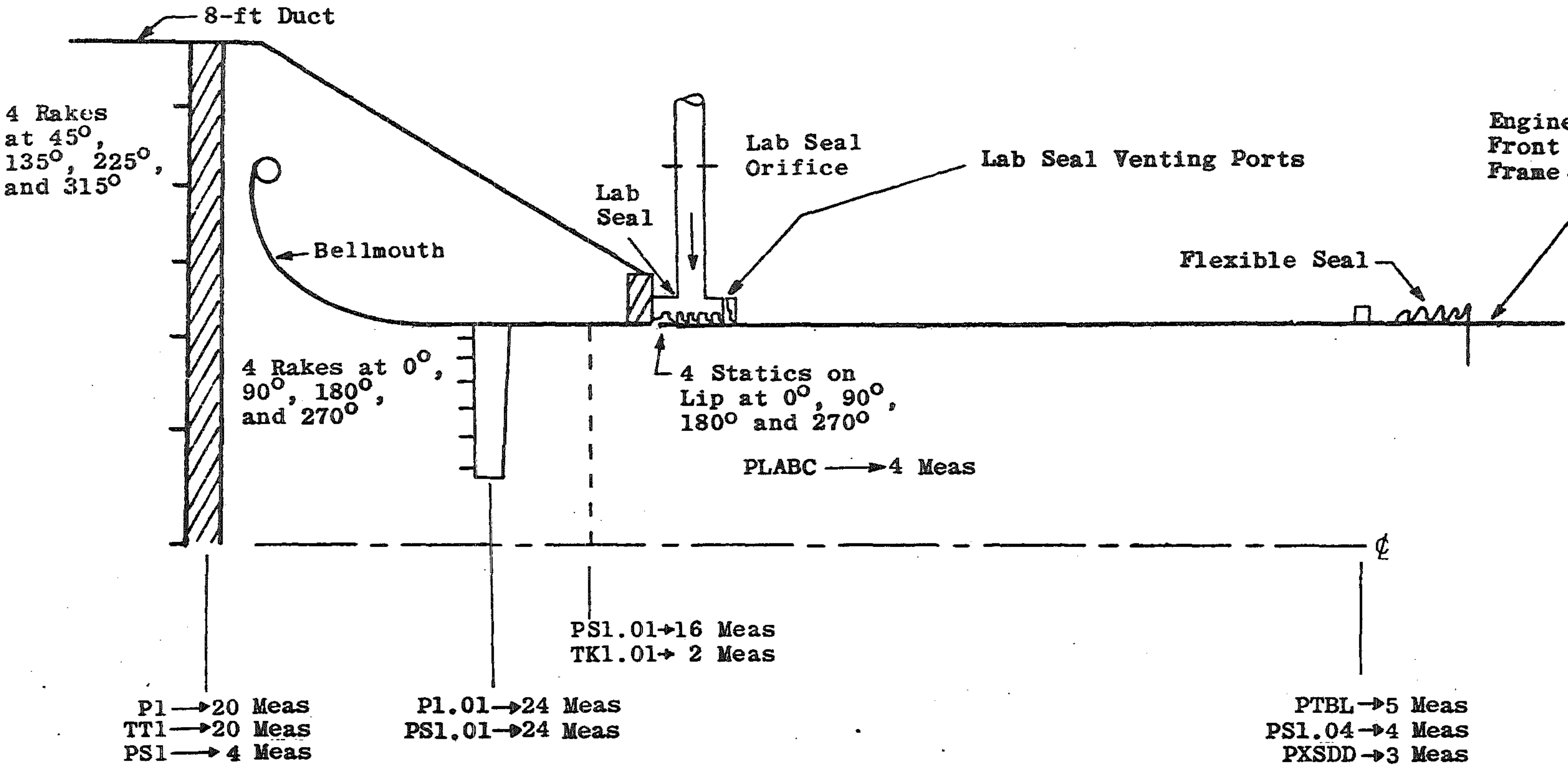
a. Fuel line installation

Figure 4. Engine connections



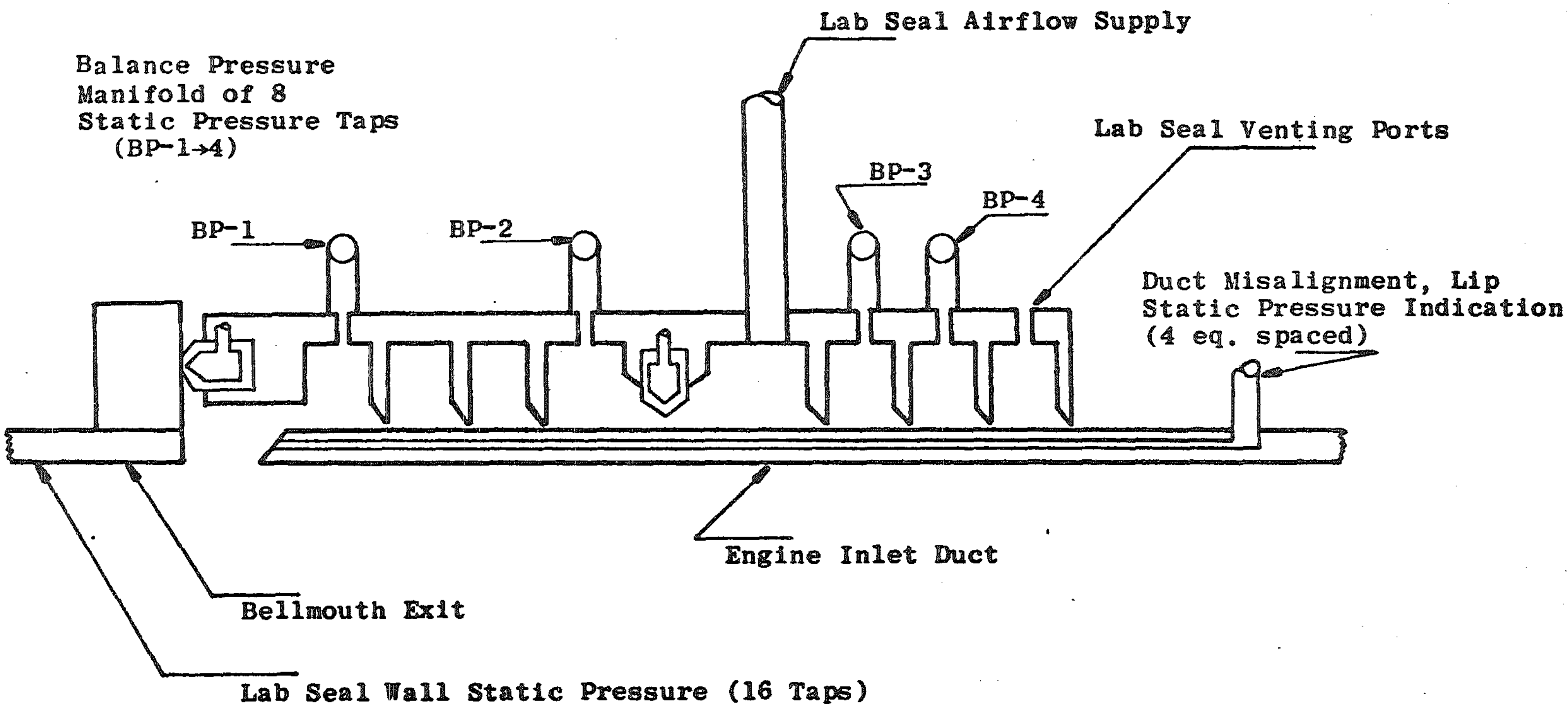
b. Pneumatic line installation

Figure 4. Continued



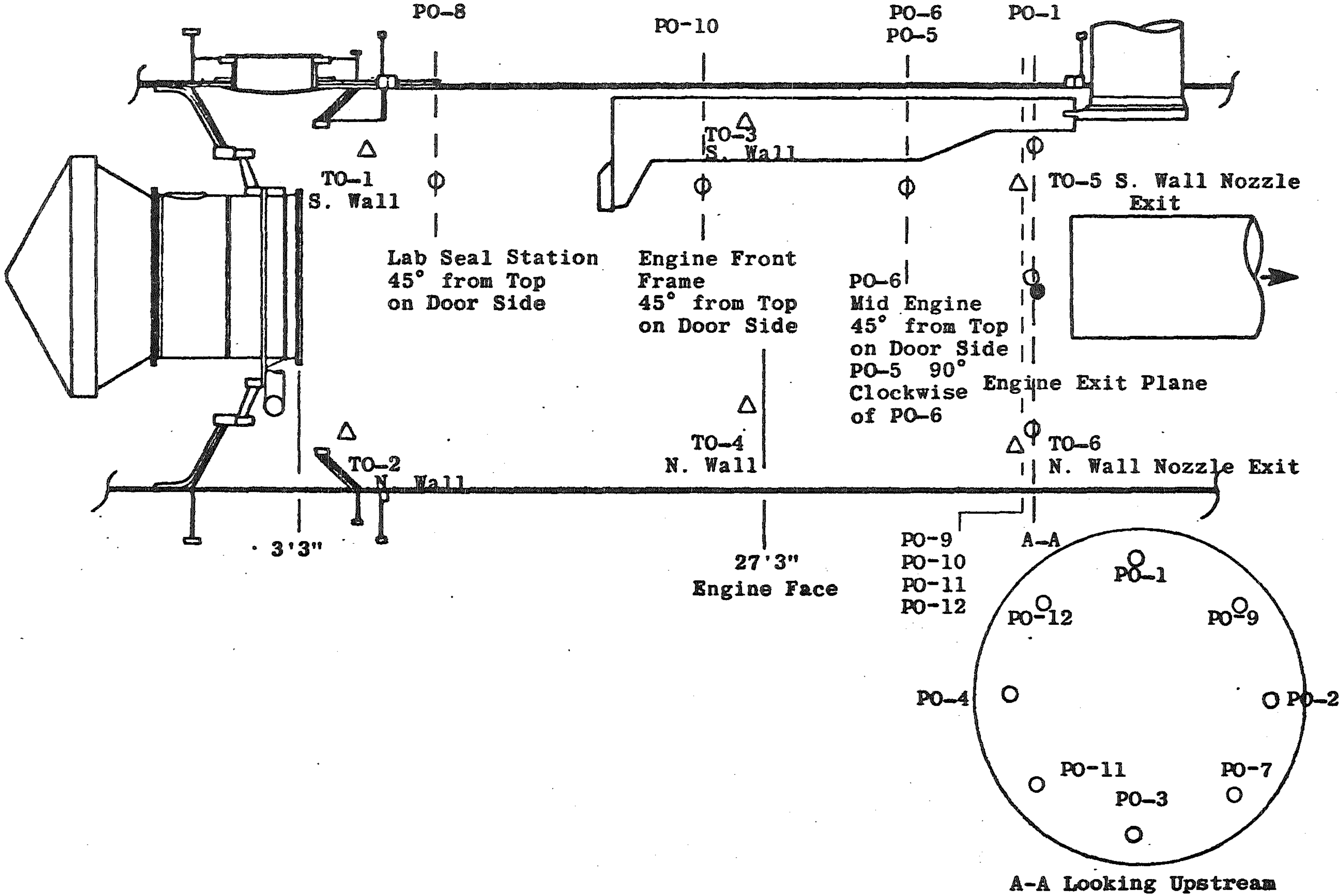
c. Lab seal installation

Figure 4. Continued



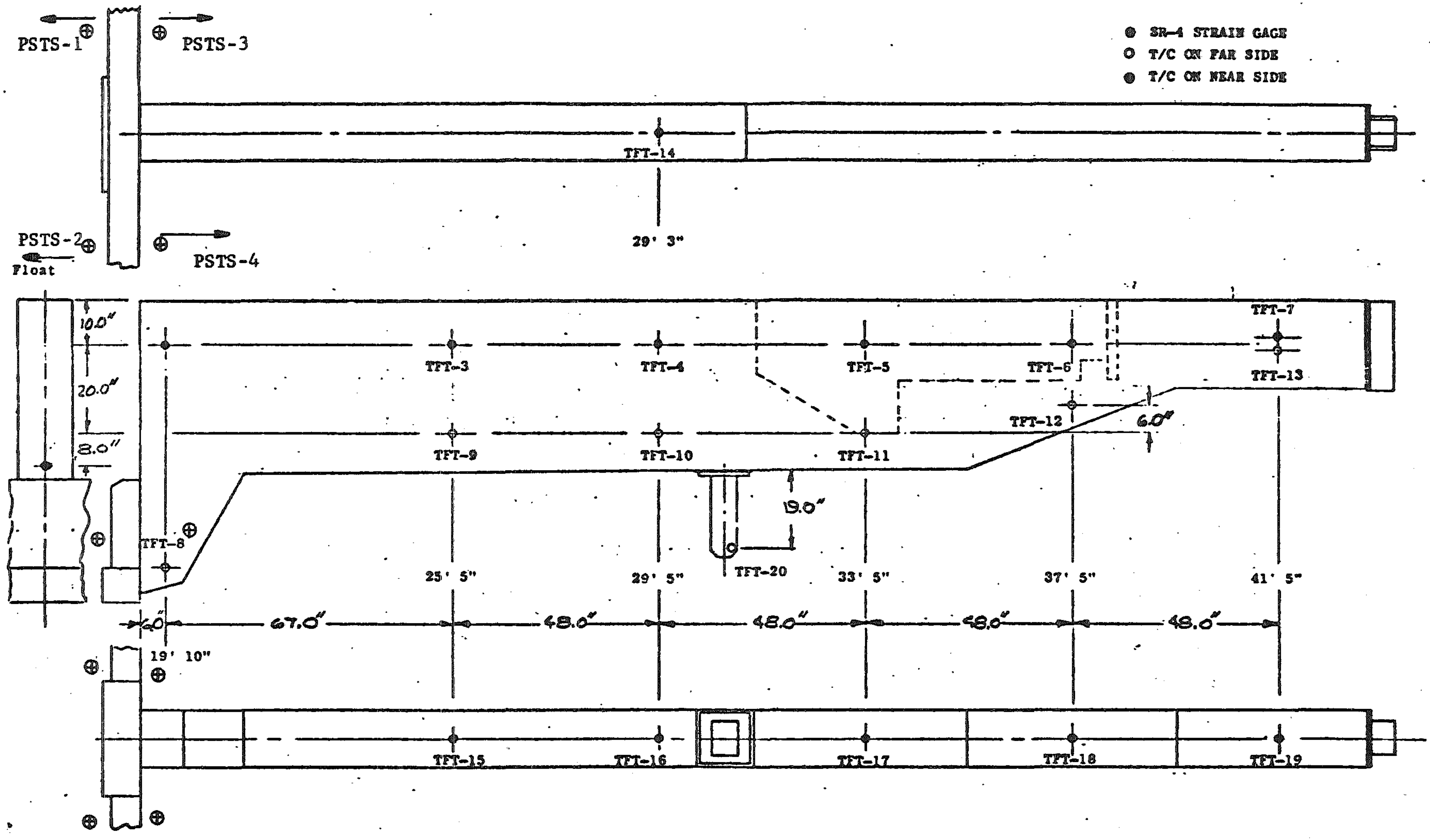
d. Lab seal detail

Figure 4. Concluded



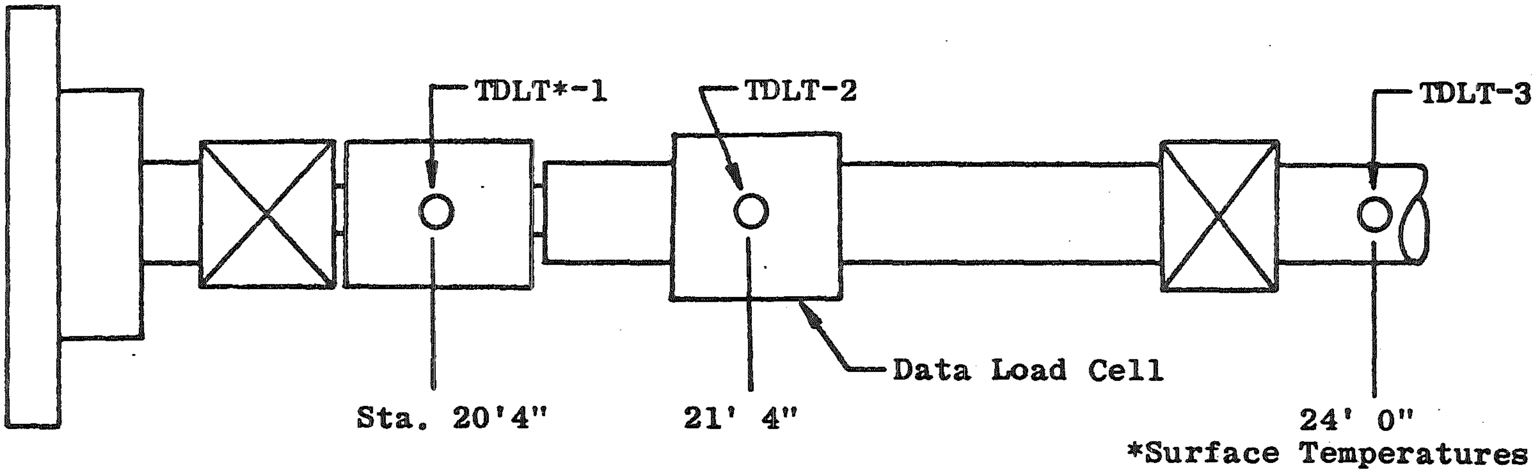
a. Test cell pressure and temperature location

Figure 5. Instrumentation locations



b. J-2 thrust stand instrumentation

Figure 5. Continued



c. Data load train temperature instrumentation

Figure 5. Concluded

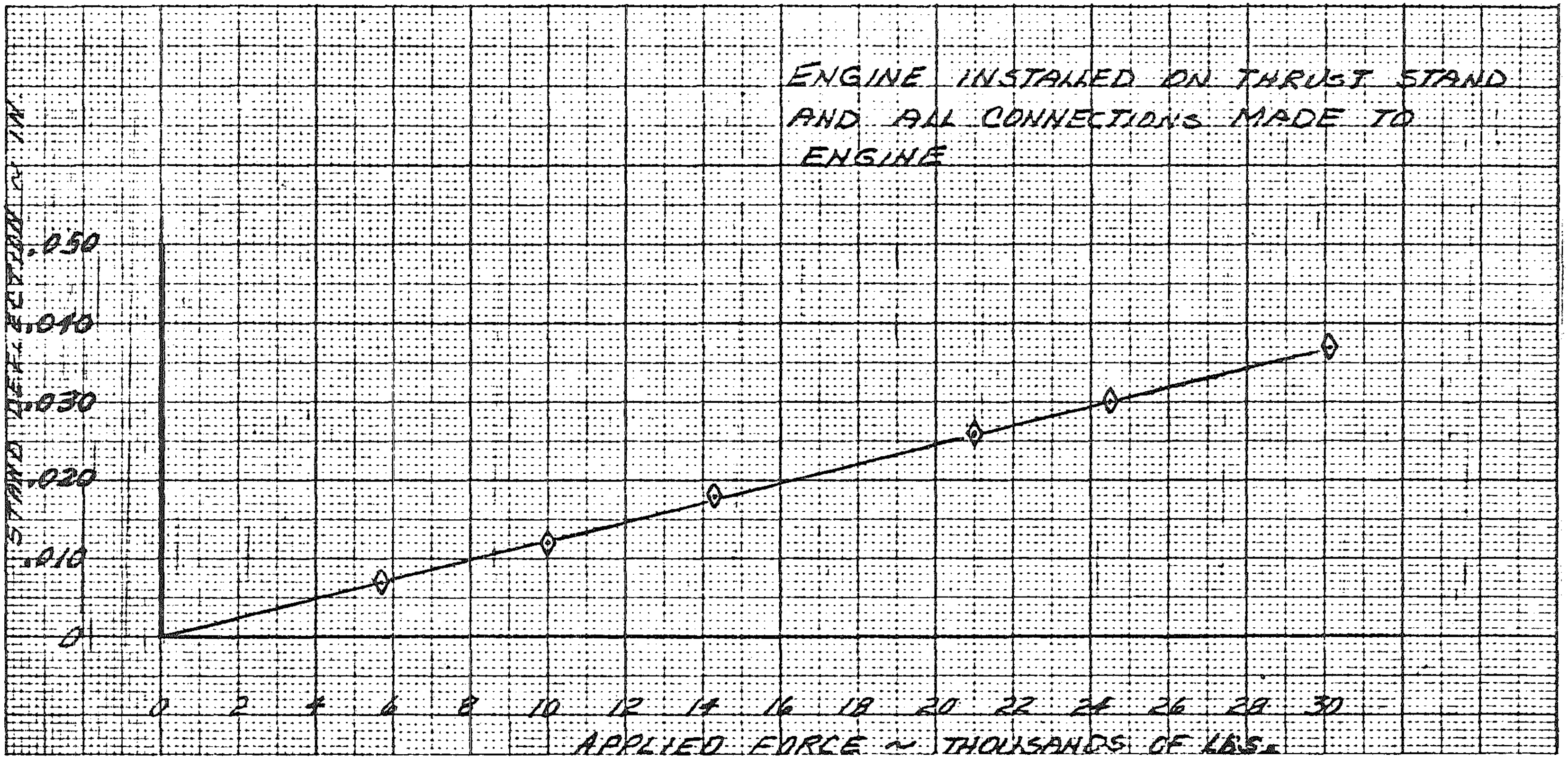


Figure 6. Thrust stand deflection measurements

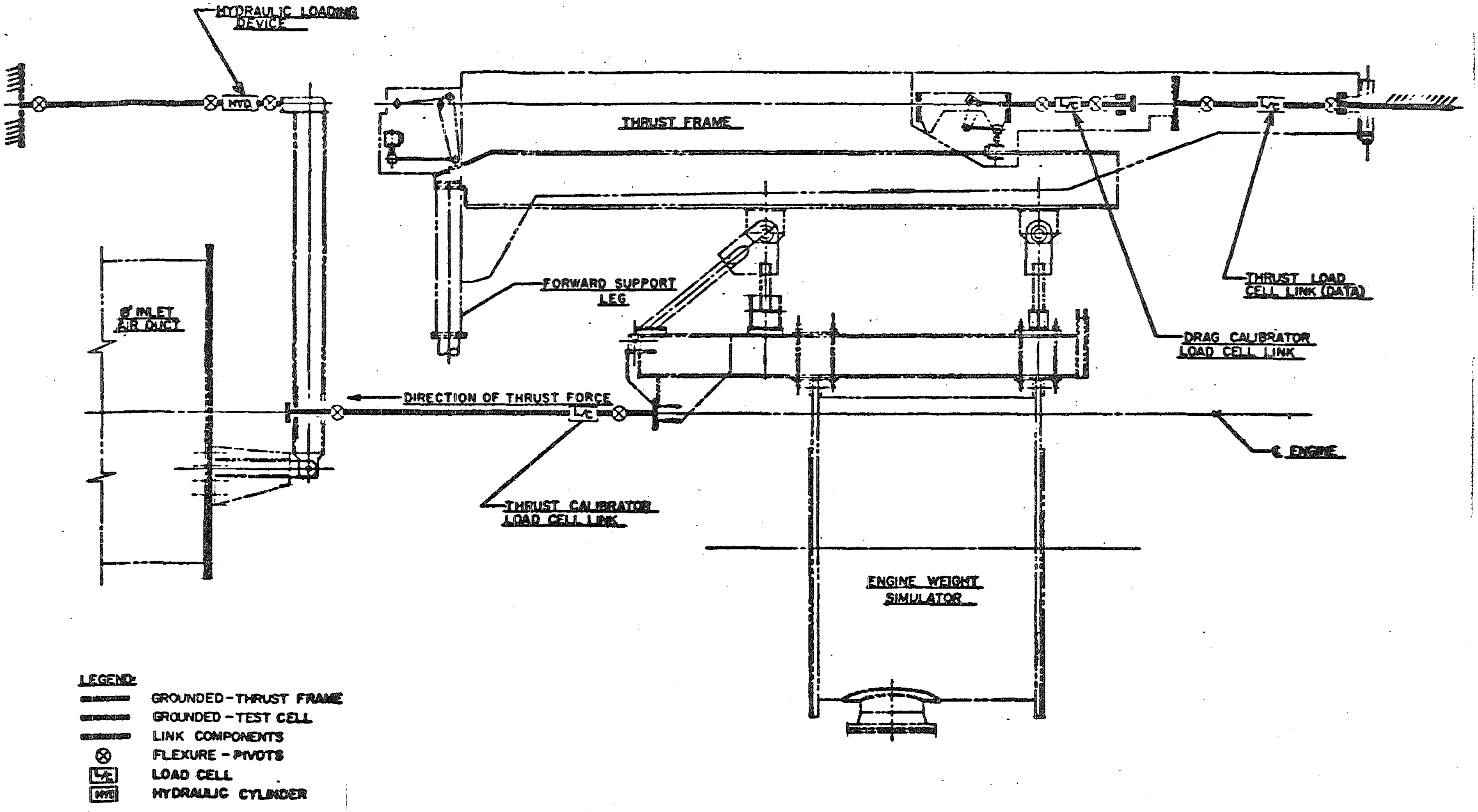


Figure 7. Installation of centerline loading hardware

ARO, INC.
TECHNICAL SUPPORT DEPARTMENT
INSTRUMENT BRANCH

STRAIN GAGE FORCE TRANSDUCER CALIBRATION REPORT
CALIBRATION DATE 06-14-74

INSTRUMENT NO.	41757 BRIDGE A	MATING CONNECTOR	CA3106E-14S-5S-F43
SERIAL NUMBER	45187	POSITIVE INPUT CONNECTION(S)	A AND
MANUFACTURER	BALDH	NEGATIVE INPUT CONNECTION(S)	D AND
MODEL NUMBER	T3P2B	POSITIVE OUTPUT CONNECTION(S)	B AND
SENSOR RANGE	+-20K LBF	NEGATIVE OUTPUT CONNECTION(S)	C AND
CALIB RANGE	- 25000.000 LBS	SHIELD CONNECTIONS	AND
PURCHASE ORDER NUMBER		FACILITY IDENTIFICATION	RNOO
WORK ORDER NO.	9873	CALIBRATION PROC.	TB40.30
ACCOUNT NO.	RL041-34KA	MANHOURS	7.0
CALIB TEMP	75. DEG F	EXCITATION VOLTAGE:	10.000 VOLTS DC
INPUT RESIST:	351.3 OHMS		
OUTPUT RESIST:	348.8 OHMS		
INSUL RESIST:	10.0 K MEG OHMS		

ACTUAL FORCE CALIBRATION DATA

APPLIED FORCE LBF	OUTPUT IN MILLIVOLTS/VOLT COMPRESSION	TENSION
0.0		0.0126
5000.000		-0.7368
10000.000		-1.4866
16000.000		-2.3867
20000.000		-2.9871
25000.000		-3.7375
20000.000		-2.9876
16000.000		-2.3875
10000.000		-1.4875
5000.000		-0.7377
0.0		0.0125

CALIBRATION SUMMARY

BRIDGE CHAR	COMPRES	TENSION
ZERO UNBAL MV/V		0.0126
C.R. SENS MV/V		-3.7500
MAX N-LIN %CR		0.0224
MAX HYST %CR		0.0240
MAX N-REPT %CR		0.0054

PREVIOUS CALIBRATION SUMMARY
LAST CALIB DATE 01-07-74

BRIDGE CHAR	COMPRES	TENSION
ZERO UNBAL MV/V	0.0129	
C.R. SENS MV/V	1.4989	
MAX N-LIN %CR	-0.0120	
MAX HYST %CR	0.0200	
MAX N-REPT %CR	0.0067	

CALIBRATION EQUIPMENT

INSTRUMENT	I-NO.	CAL DATE
DW MACHINE COX	30699	12-73
VOLT BOX L&N	13444	5-74
VOLT METER DATA	53893	6-74
MEGGER KEITHLEY	31830	6-74
BRIDGE RUBICON	13463	6-74

CALCULATED SHUNT R-CAL EQUIVALENTS
R-CAL TYPE DOSP1
R-CAL IDEN: 577 DOUBLE SHUNT
POSITIVE R-CAL APPLIED ACROSS AB AND DC
NEGATIVE R-CAL APPLIED ACROSS AC AND BD

R-CAL STEP	NOM RES K OHMS	OUTPUT MV/V	EQUIVALENT FORCE LBF
RN1	200.000	0.8812	N/A
RN2	100.000	1.7484	N/A
RN3	66.666	2.6130	N/A
RN4	50.000	3.4776	N/A
-RN1	200.000	-0.8562	-5793.54
-RN2	100.000	-1.7235	-11576.57
-RN3	66.666	-2.5881	-17339.78
-RN4	50.000	-3.4527	-23102.05

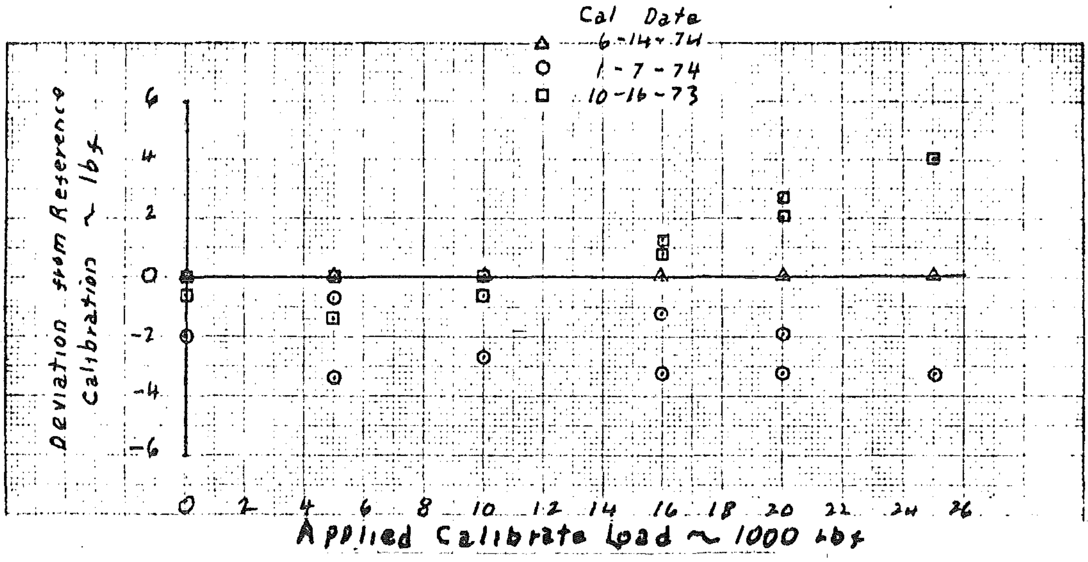
* LINEAR EXTRAPOLATION

REMARKS:

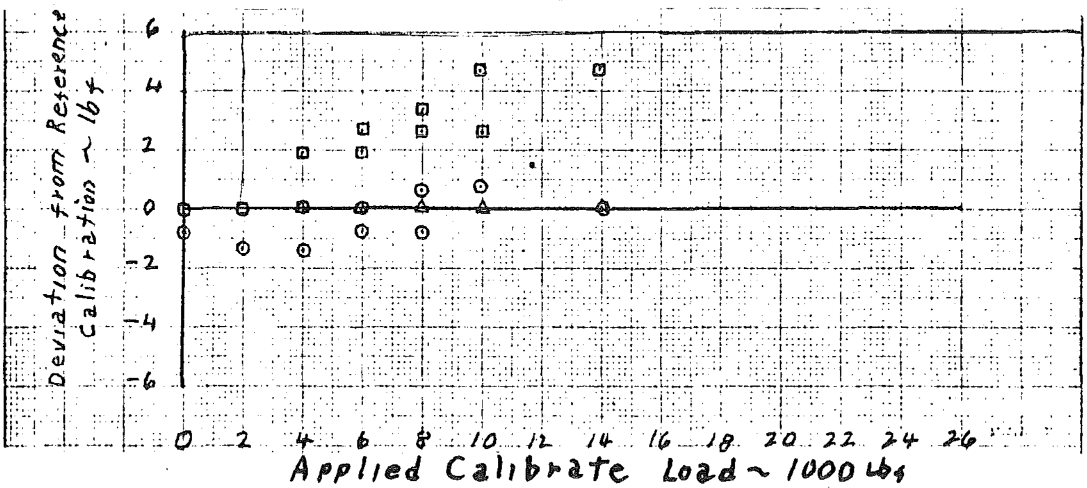
CAL BY 286T CAL ENGR

ARO INC ESP QC APPROVED E-15

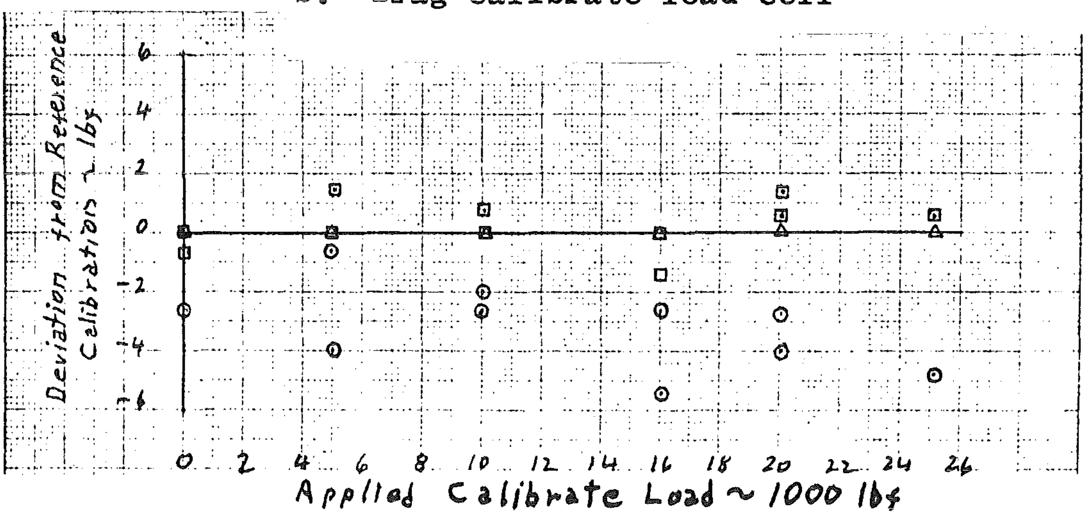
Figure 8. Standards laboratory-load cell calibration report



a. Data load cell

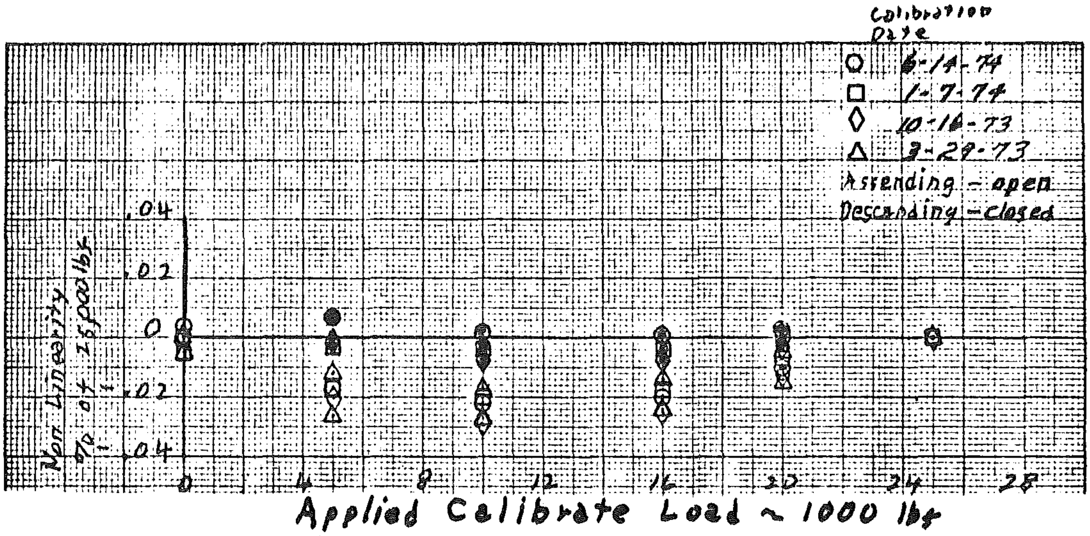


b. Drag calibrate load cell

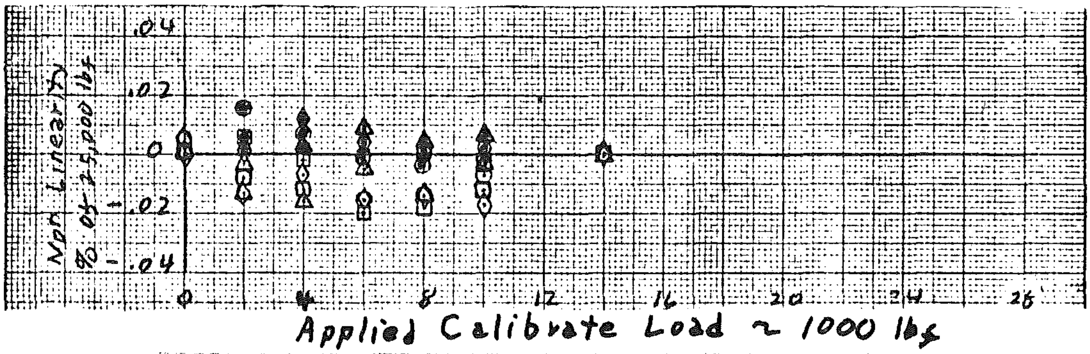


c. Thrust calibrate load cell

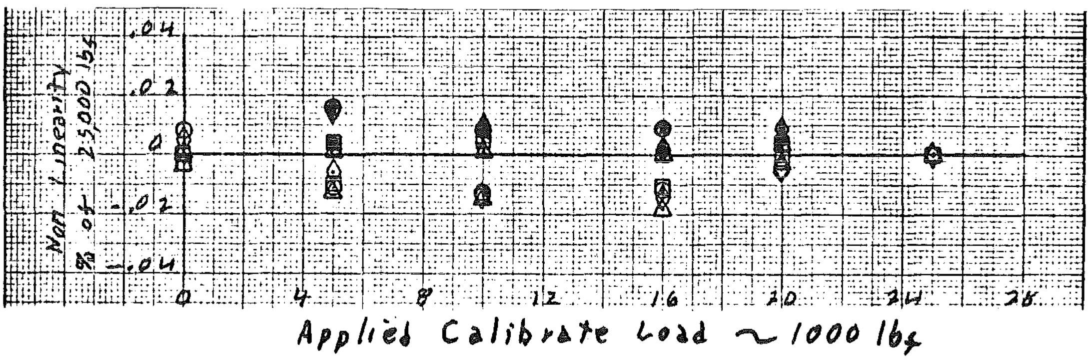
Figure 9. Load cell repeatability during lab calibration



a. Data load cell linearity



b. Drag calibrate load cell linearity



c. Thrust calibrate load cell linearity

Figure 10. Load cell linearity during lab calibration

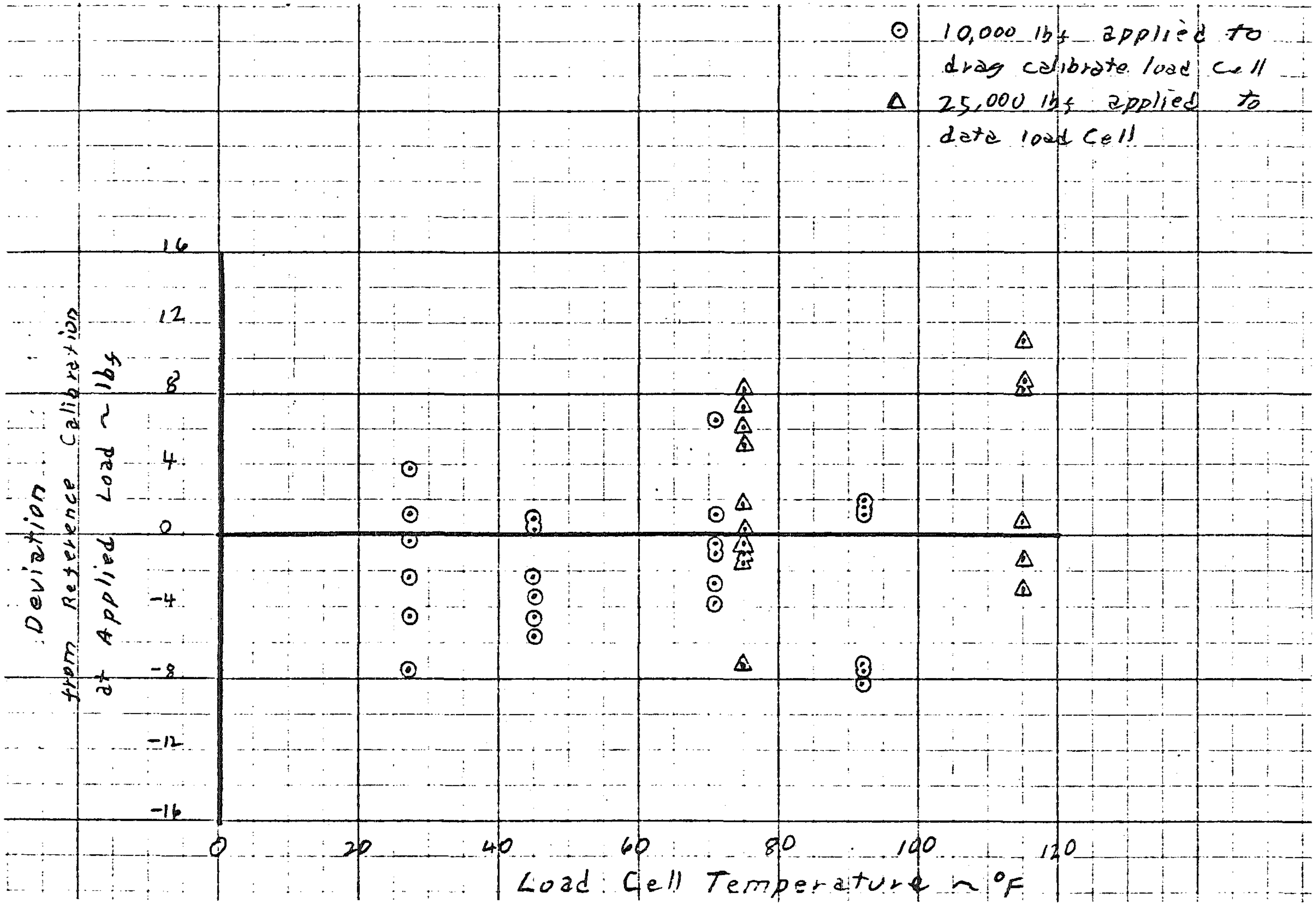


Figure 11. Laboratory calibration of temperature effect on load cell

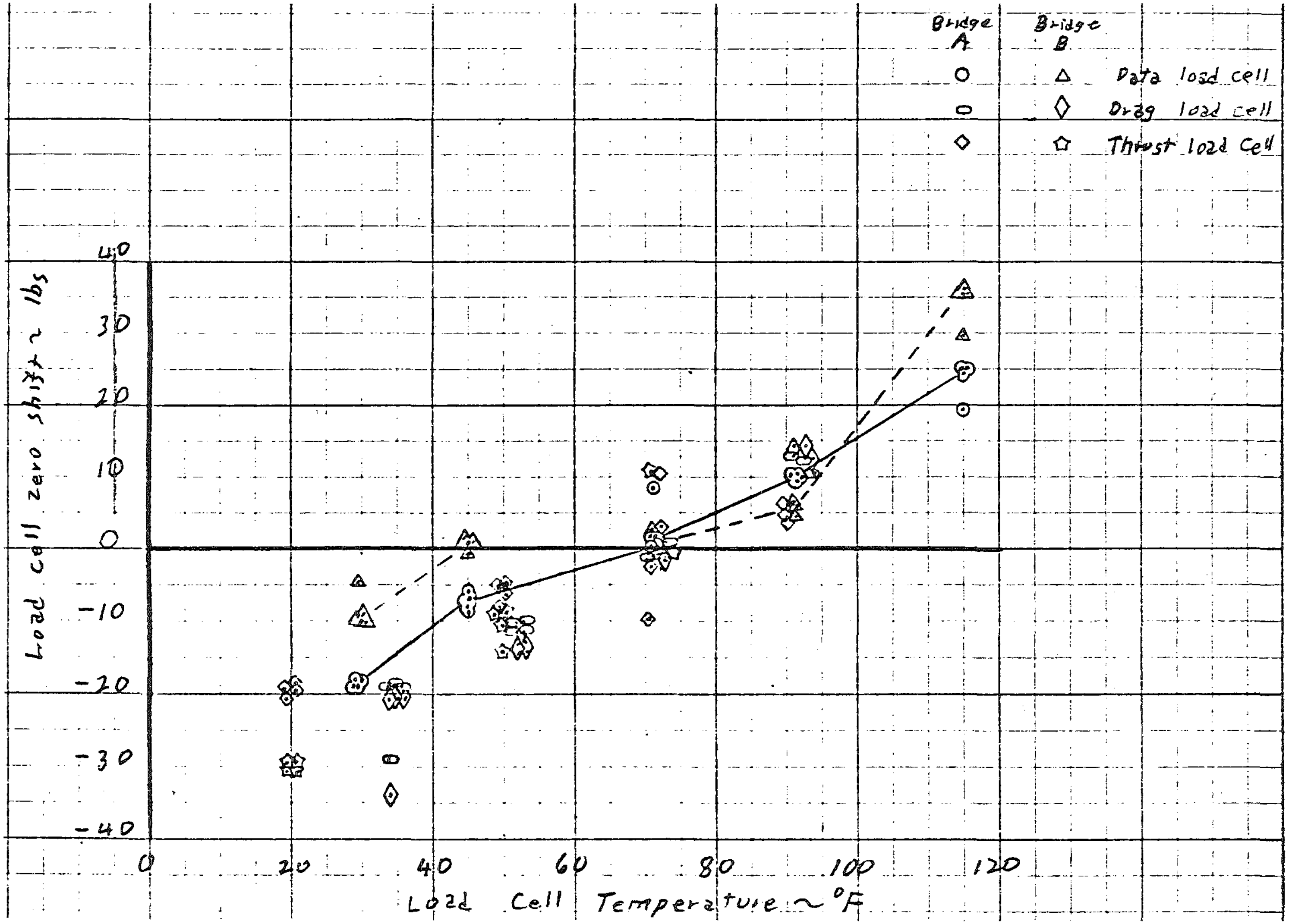
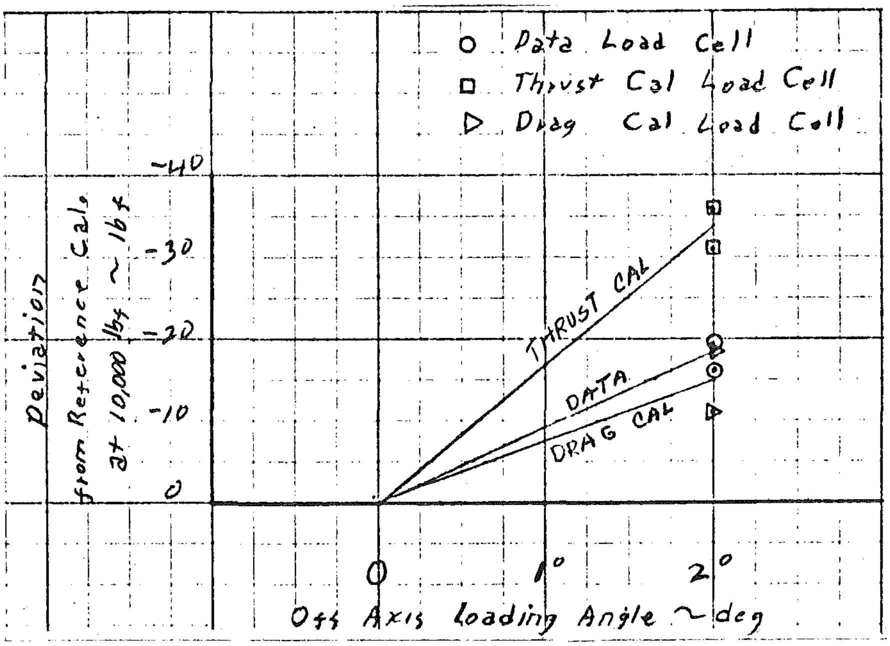
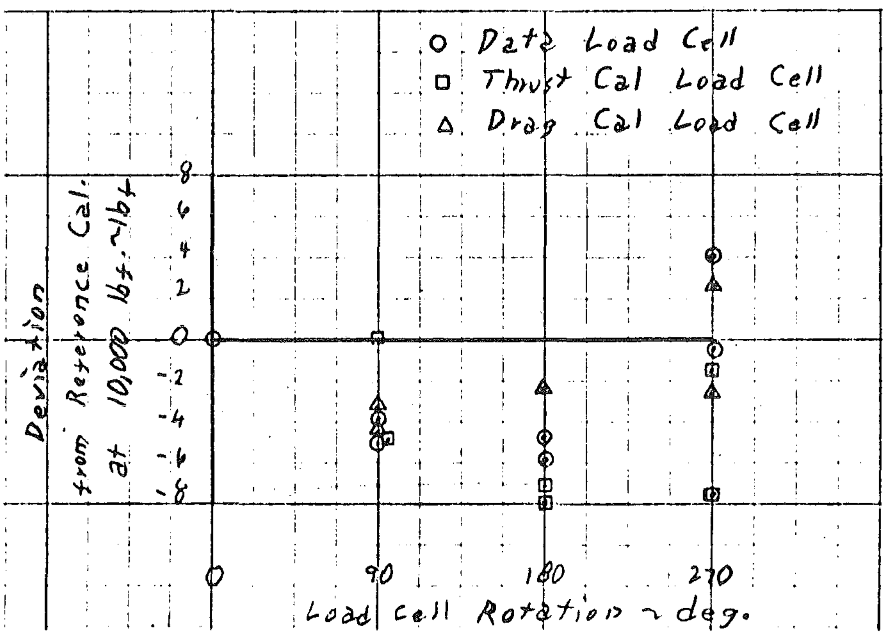


Figure 12. Load cell zero shift as a function of temperature



a. Effect of off axis loading



b. Effect of rotation

Figure 13. Off axis loading calibration

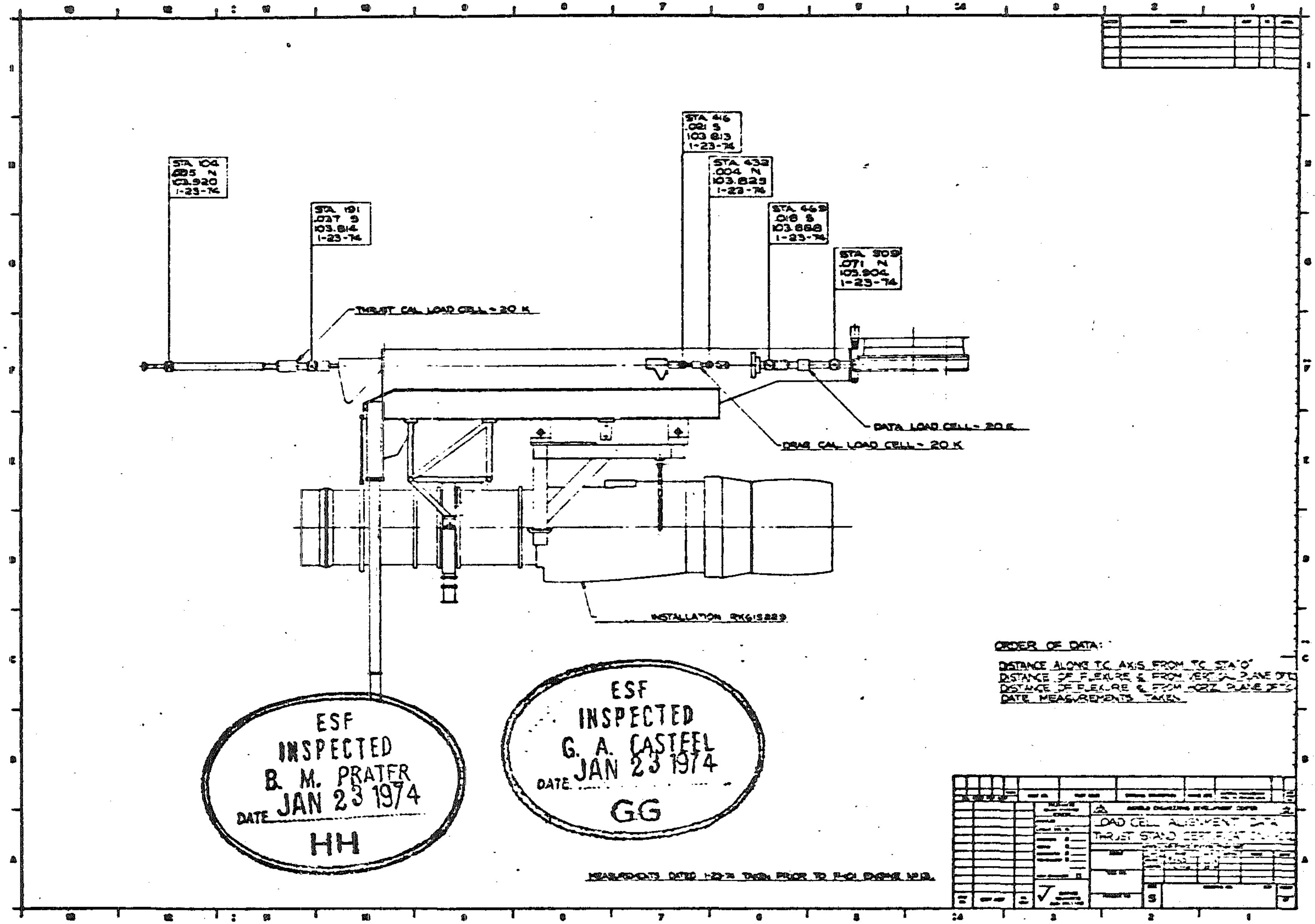


Figure 14. Thrust stand alignment certification

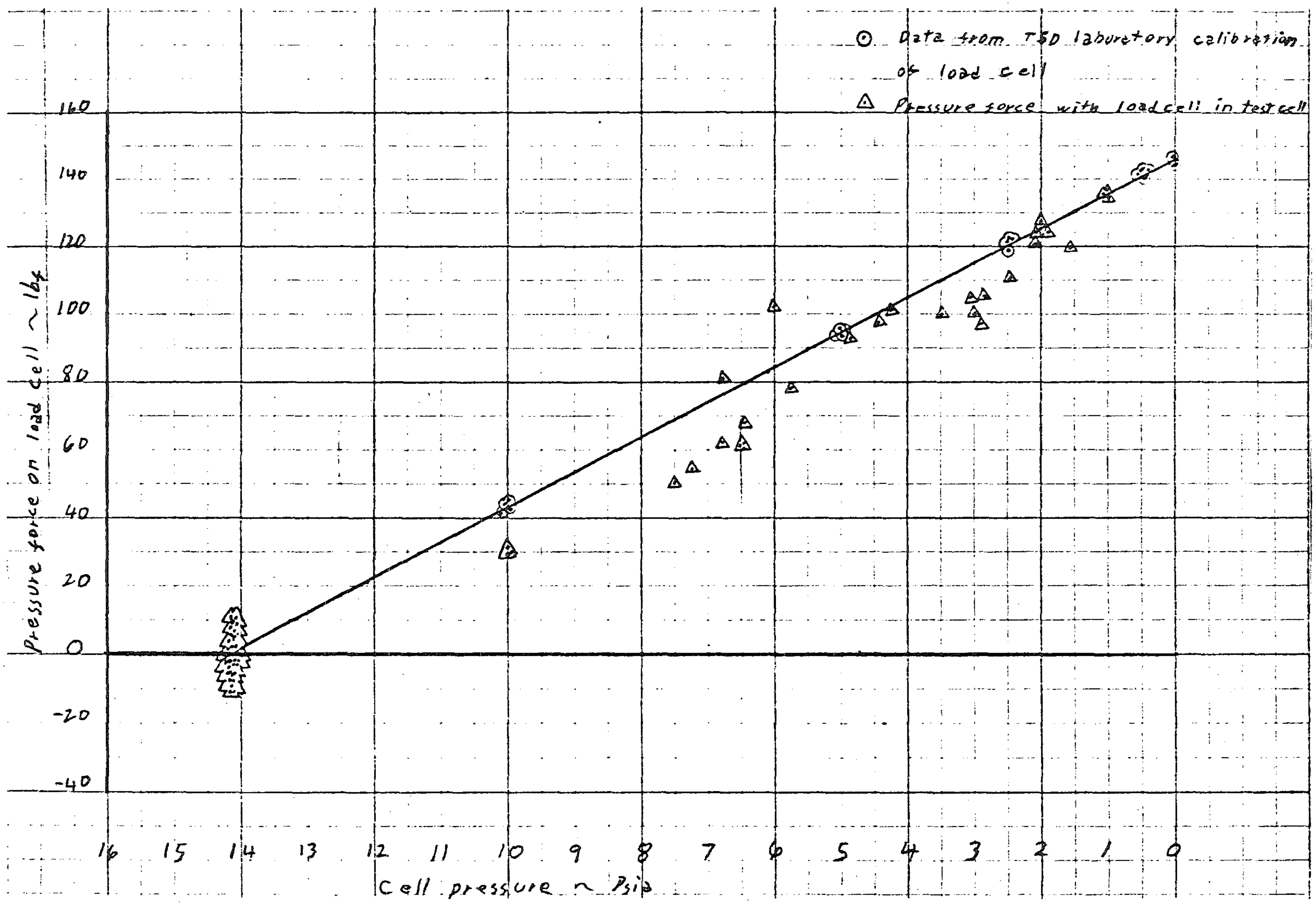


Figure 15. Pressure effect on the load cell and test cell

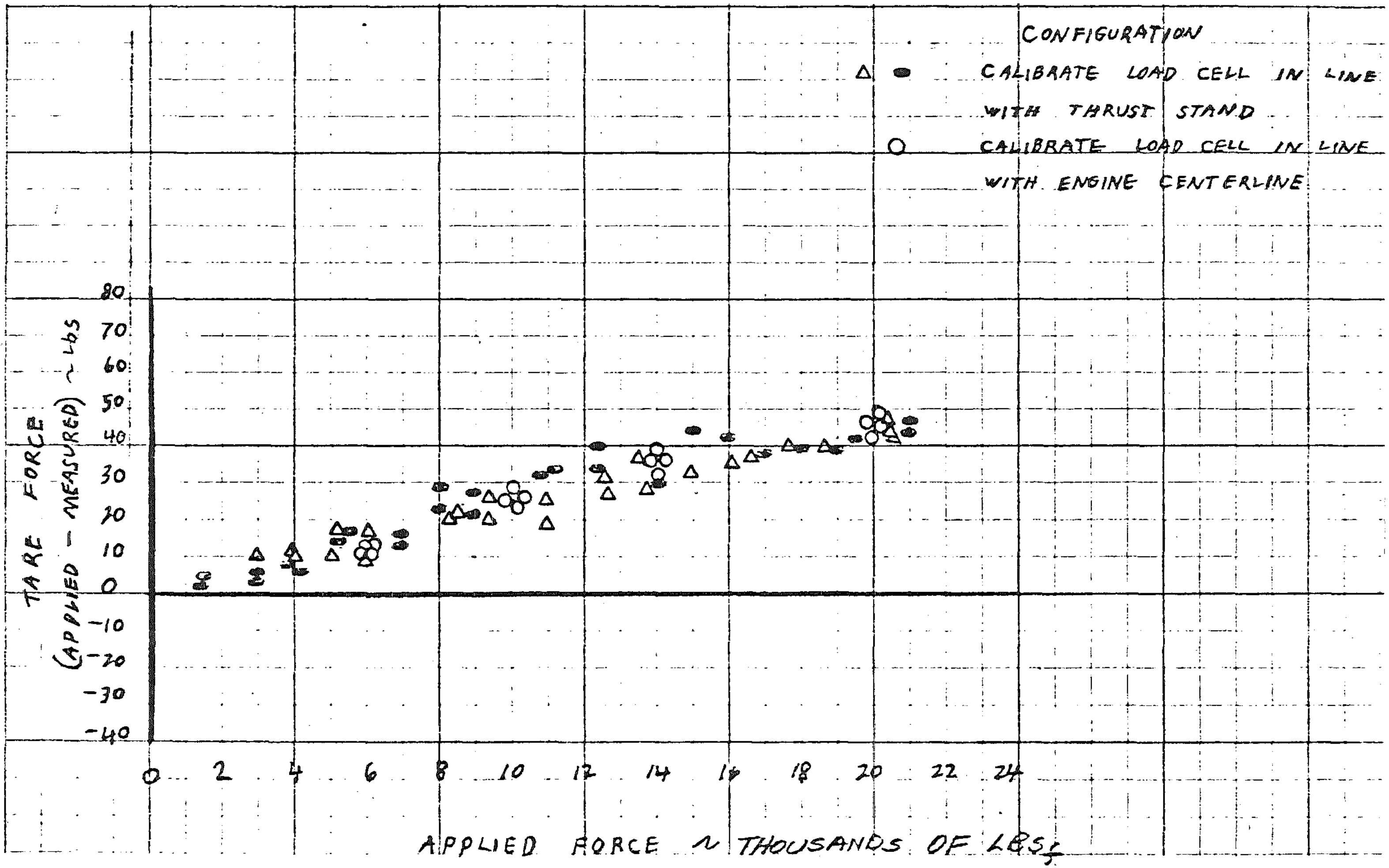


Figure 16. Centerline force calibration

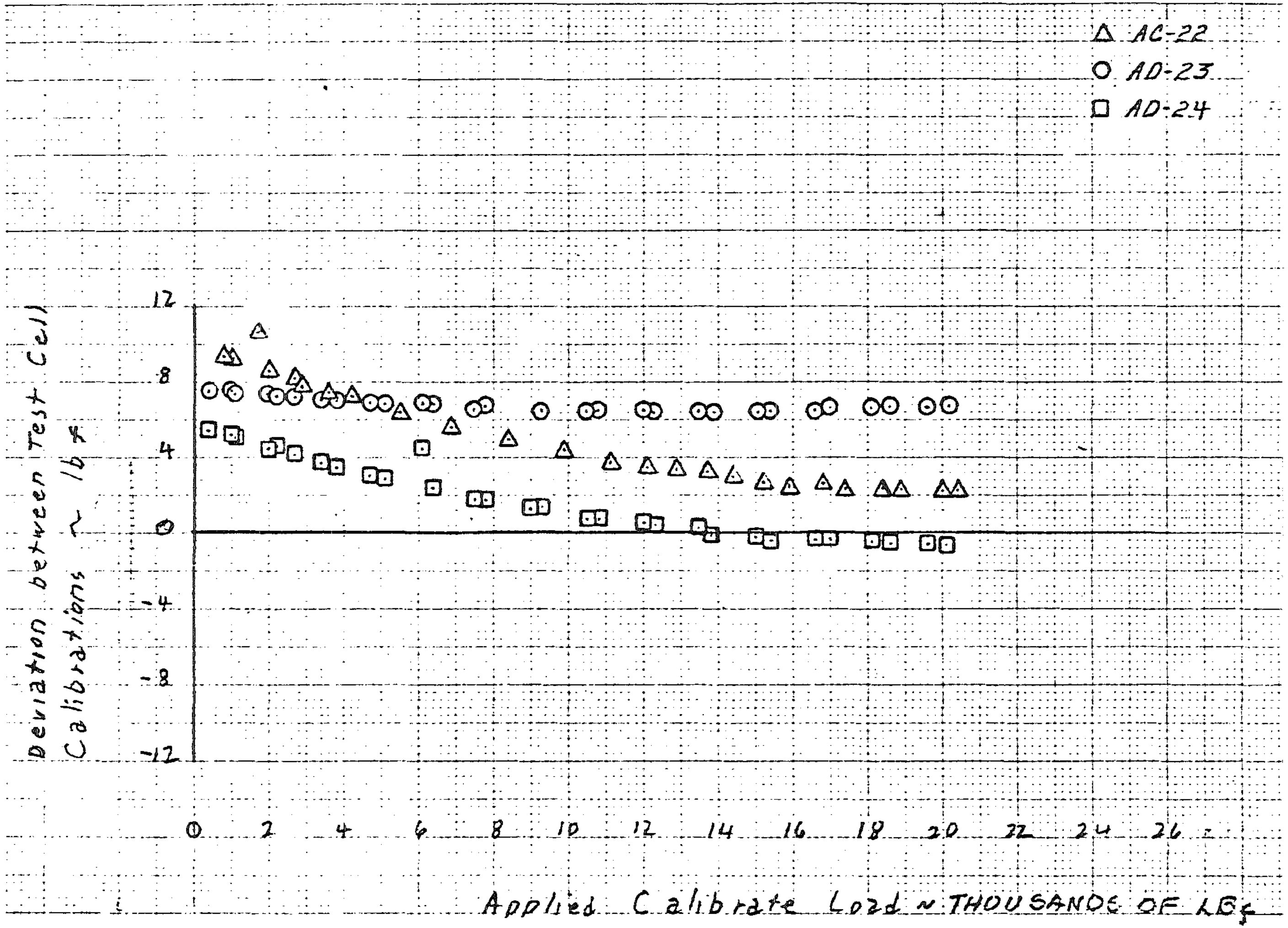


Figure 17. Deviations between pre- and posttest calibrations

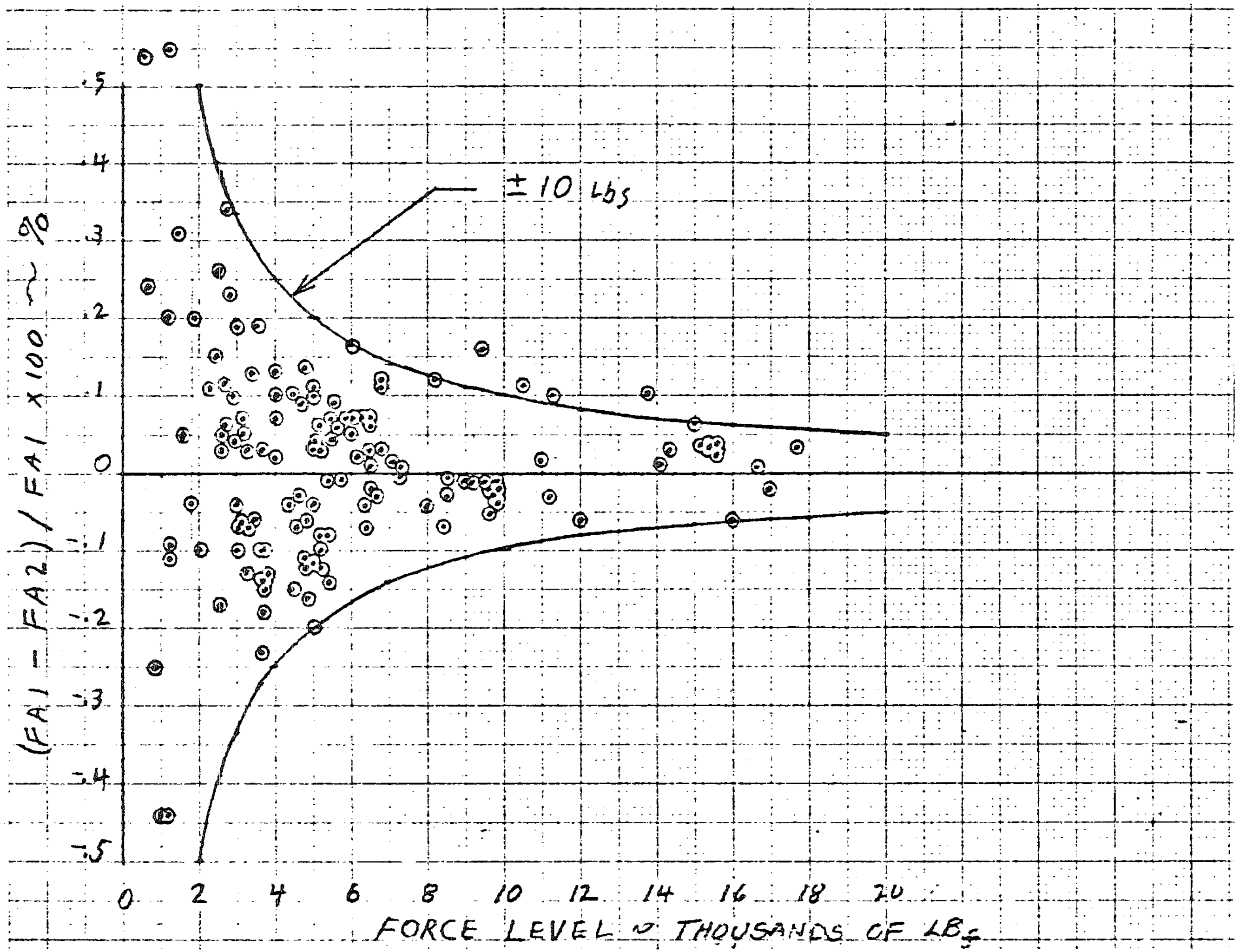


Figure 18. Difference in data load cell bridges

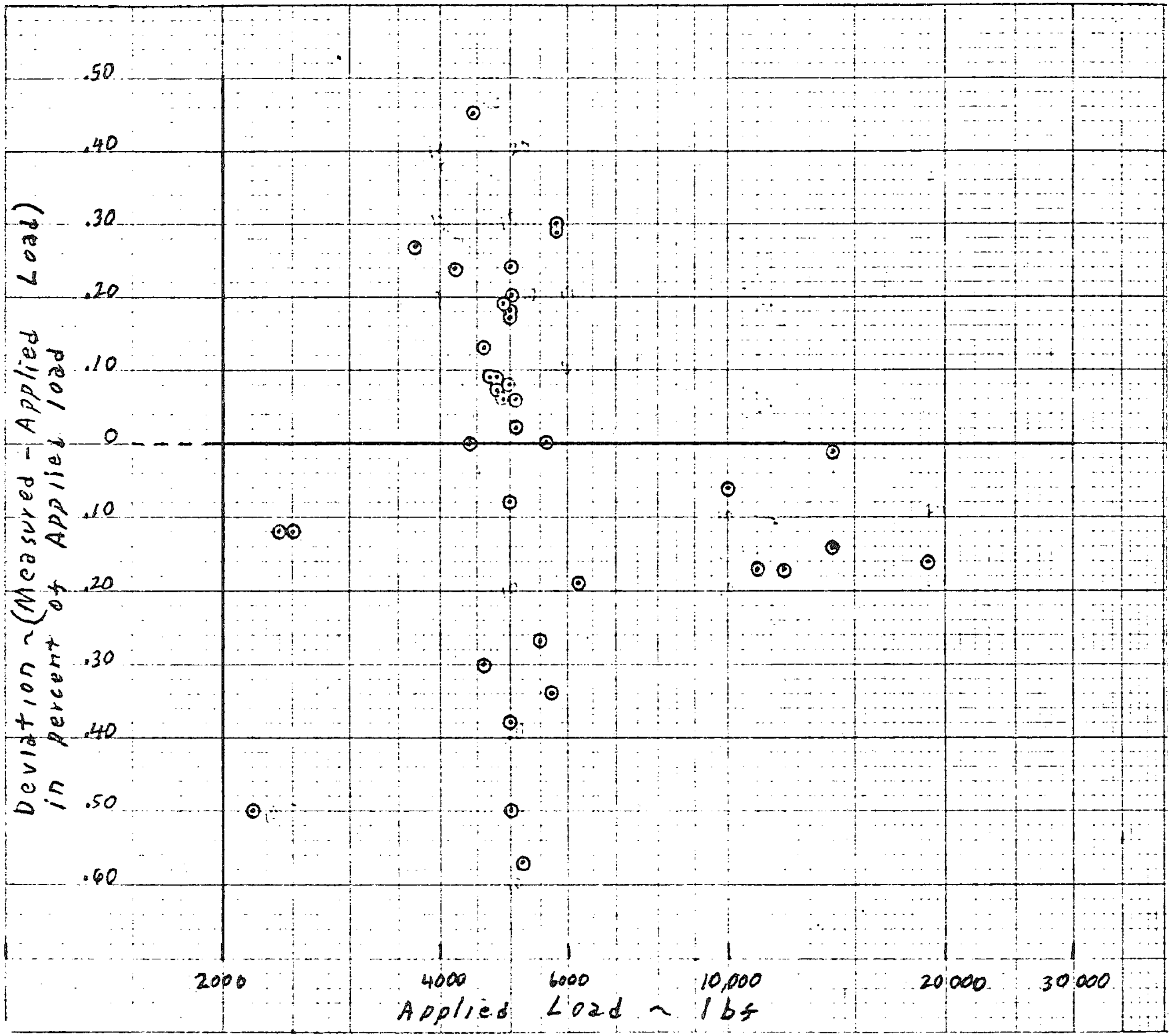


Figure 19. Deviation obtained during applied load test

TABLE 1 THRUST STAND UNCERTAINTIES

Range / Source	< 5000 lb_f		5000 → 10,000 lb_f		10,000 → 15,000 lb_f		15000 → 20000 lb_f	
	bias	$t_{95}S$	bias	$t_{95}S$	bias	$t_{95}S$	bias	$t_{95}S$
Lab Standard	.155	-	3.10	-	6.15	-	11.75	-
Calibrator System at Zero	3.78	5.78	3.78	5.78	3.78	5.78	3.78	5.78
Thrust Cal	1.16	2.01	1.19	2.57	5.65	5.49	6.23	9.24
Applied Load Tests	1.17	4.36	1.44	5.42	1.10	3.39	1.10	3.39
Data Load Cell	5.55	10.42	5.18	10.77	7.46	14.27	8.97	12.40
Total	7.08	12.84	7.36	13.61	11.60	16.70	16.52	16.85
	19.93		20.97		28.29		33.37	

APPENDIX A

THE J-2 INPLACE THRUST CALIBRATION PROGRAM

The calibration takes approximately three minutes for both the thrust and drag directions and the data system records 100 records equally spaced during this time interval. The record number of each record appears under the heading of "Rec. No." on the first column of Fig. A1 through Fig. A6. Figures A5 and A6 present the data from the drag portion of the calibration which is conducted first; therefore, the record numbers begin at three and go through 34. Figure A5 contains the data for the applied drag load and the drag force measured with FA-1. Figure A6 contains the data for the same applied load and the drag force measured with FA-2. Figure A1 thru Fig. A4 contain the data for the applied thrust load and the record number goes from 36 through 100. Figures A1 and A2 apply to the thrust force measured with FA-1 and Figs. A3 and A4 apply to the thrust force measured with FA-2. The thrust loading cycle will be discussed first. A thrust force applied to the stand by the gear mechanism is transmitted through the calibrate load cell. The counts from FACT-1 and FACT-2 during the thrust loading are tabulated in the 2nd column, Fig. A1 (FACT-1, channel number 72) and Fig. A3 (FACT-2, Channel Number 73). A set of resistance cals (R-Cal) is applied to these count levels to convert the counts to lbs of applied force for FACT-1 and FACT-2. These are both estimates of the same applied force so the two calculated forces are averaged and the average is tabulated in Column 4, Fig. A1 (FACT AVG. APP. R-CAL LD) and Col. 4, Fig. A3. The deviation of each reading (FACT-1 and FACT-2) from this average is tabulated in Column 3, Fig. A1, and Column 3, Fig. A3. This deviation is used to check the agreement of the two bridges of the cal load cell. Eighty to ninety percent of these deviations should be below 15 lbs to have good agreement between the two bridges. When the deviations are random (+) and (-), it is a result of noise and can be averaged out if the deviation is biased either (+) or (-) it is a result of the R-cals for one of the bridges varying from the norm.

Column 5, Fig. A1, is a tabulation of the counts from the data load cell (FA-1 Bridge A) and to obtain the relationship of the applied load to the measured data a least square curve fit is obtained of load applied as a function of measured counts (Col. 4 vs. Col. 5). This curve fit is of the form of $F = A + BX + CX^2$ and the constants (A, B, C) are tabulated directly above Columns 2 through 5 and titled "Positive Thrust Coefficients" (Fig. A1). These coefficients relate FA-1 to the applied load and to evaluate the goodness of curve fit the curve is applied to Col. 5 to determine an FA-1 calculated load (Col. 6). The difference in the applied load (Col. 4) and the calculated load (Col. 6) is determined and tabulated (lbf) in Col. 7 titled "error." This represents the curve fit error and is also tabulated in Col. 8 in percent of 30,000 lbf. The curve fit is also evaluated at a no-load condition (RN-0) to determine its zero force intercept. The count level at RN-0 is used in the equation to obtain the value titled RN-0 shown above Col. 10, Fig. A1 and should be 10 lbs or less. The value titled "CXX" tabulated to the left (Fig. A1) of the RN-0 value represents the nonlinearity of the 2nd degree curve The primary purpose of the inplace thrust calibration is to obtain the coefficients for the 2nd degree curve; however, additional information is printed out on Fig. A1 to aid in trouble shooting the thrust system.

Column 5 is the count signal from the data load cell and by applying the R-cals for this channel the calculated force tabulated in Col. 9 is obtained. This force is used to determine the tare load on the stand but is not used in test data processing. The tare load is calculated as (FACT AVG. APP. R-CAL LD) - (FA-1 R-CAL LD) or as (Col. 4 - Col. 9) and is tabulated in Col. 10. This tare load (Col. 10) is also plotted on Fig. A7 for tare 1 (using FA-1) and Fig. A8 for tare 2 (using FA-2). These can have ±10 lbs scatter but should be linear. To help compile a history of the stand characteristics, a least square curve fit is applied to the tare load (Col. 10) and the constants (A, B, C) for this curve are titled, "Positive Tare Coefficients" and are listed directly above Col. 7 through Col. 10, Fig. A1. The curve using these constants are evaluated at load levels of 5,000, 10,000 and 20,000 lbs, and this calculated tare is tabulated as "calculated tare", Fig. A1. These tare loads should be repeatable (±8 lbs) from calibration to calibration.

The thrust calibration program applies the same procedures discussed previously on the remaining thrust channel (FA-2) and both data bridges (FA-1, FA-2) for the drag cycle. The data are shown in Fig. A3 through Fig. A10, but will not be discussed.

Several major areas can be checked to evaluate a thrust cal and are discussed as follows:

1. Column 2 - Cal load cell deviation from avg.

   a. Eighty to 90 percent of these should be:

      < 15 lbs, thrust cycle
      < 10 lbs, drag cycle

2. Column 7 - curve fit error

   a. This should compare closely with Col. 2 and the limits will be the same.

   b. This includes one bridge of the data load cell and a bad bridge or stand interference will indicate large deviations (consistent deviations > 20 lbs)

3. Column 9 - R-cal data load

   a. This should start at zero (± 10 lbs) check beginning and end of drag cycle

4. Column 10 and Fig. 7 - Tare

   a. Tare should be linear (± 15 lbs)
   b. Hysteresis < 15 lbs
   c. Calculated tare at 5K, 10K and 20K should compare to previous cals (± 10%)

5. RN-0 Load

   Should be zero (± 10 lbs)

6. Column 4, Column 9

   a. The max load should not go above 25,000 lbs or the count level in Cols. 2 and 5 will be approaching 16,383 which is a SEL max level.

ENGINE TEST FACILITY
TEST CELL: J-2
TEST ARTICLE:
TEST ARTICLE S/N:

TEST DATE: 3- 3-75 726 HRS
COMP DATE: 3-12-75 1032 HRS
COMP RUN: OFF LINE
PROGRAM: THRUST CALIBRATION

TEST: CG13 DATA POINT: 5302
PROGRAM REVISION NO. I
INSTRUMENT BOOK REVISION NO. 09
FLIGHT NOZZLE TEST

R-CAL 5401

LOAD	TARE	LOAD	TARE	LOAD	TARE	CXX	RNO
.50000+04	.24318+02	.10000+05	.44936+02	.20000+05	.68918+02	-.69238+02	-.16874+01

	POSITIVE THRUST COEFFICIENTS			POSITIVE TARE COEFFICIENTS	
A	B	C	A	B	C
.613235+02	-.161122+01	-.446176-06	-.205184+01	.584913-02	-.115032-06

REC. NO.	CH.NO.72 FACT-1 COUNTS	FACT-1 DEVIATION FROM AVG.	FACT AVG.APP. R-CAL LD	CH.NO.68 FA-1 COUNTS	FA-1 CALC.LOAD	ERROR	PERCENT ERROR	FA-1 R-CAL LD	FACT.FA-1 R-CAL LD DELTA
36	231.8000	0.9009	4.0761	42.0000	-6.3486	10.4246	0.0347	-4.6264	8.7024
37	230.8000	4.6491	1.9391	37.9000	0.2576	1.6815	0.0056	1.9344	0.0047
38	232.1111	0.6816	3.7941	39.2000	-1.8370	5.6311	0.0188	-0.1485	3.9426
39	229.6000	2.8820	5.6397	39.1111	-1.6938	7.3335	0.0244	-0.0063	5.6461
40	225.4000	6.2761	9.0129	39.1000	-1.6759	10.6888	0.0356	0.0114	9.0015
41	222.1000	5.9294	14.6767	35.1000	4.7691	9.9076	0.0330	6.4213	8.2554
42	219.5000	2.4832	22.3121	28.6000	15.2422	7.0699	0.0236	16.8374	5.4748
43	218.0000	2.0013	25.2110	25.8899	19.6105	5.6005	0.0187	21.1818	4.0292
44	210.4000	2.5832	36.8746	24.0000	22.6540	14.2206	0.0474	24.2087	12.6659
46	206.2222	1.8168	44.3724	18.7000	31.1935	13.1789	0.0439	32.7018	11.6706
47	202.5000	0.0886	52.0981	10.9000	43.7612	8.3369	0.0278	45.2011	6.8970
48	35.7000	10.3464	310.5972	-145.9000	296.3913	14.2059	0.0474	296.4683	14.1290
49	-598.3000	4.2205	1338.2572	-779.7000	1317.3217	20.9354	0.0698	1312.1132	26.1439
50	-1291.6000	6.5193	2453.0400	-1476.0000	2438.5145	14.5255	0.0484	2427.9126	25.1274
51	-2029.5000	7.2779	3641.2248	-2212.7000	3624.2890	16.9358	0.0565	3608.4516	32.7731
52	-2778.0000	1.6441	4852.8812	-2966.2000	4836.6033	16.2779	0.0543	4815.9122	36.9690
53	-3657.4000	1.3971	6269.2144	-3851.0000	6259.5208	9.6935	0.0323	6232.9159	36.2984
54	-4612.5556	5.0546	7801.8569	-4805.8889	7794.3701	7.4868	0.0250	7760.1032	41.7537
55	-5566.4444	9.3775	9331.7966	-5756.4444	9321.4461	10.3505	0.0345	9280.3600	51.4366
56	-6511.7000	5.8842	10855.6665	-6706.4444	10846.8239	8.8426	0.0295	10799.7282	55.9383
57	-7482.9000	6.7894	12416.1222	-7683.6667	12415.0712	1.0510	0.0035	12361.5521	54.5701
58	-8441.4000	12.1893	13951.0561	-8639.8000	13948.6501	2.4060	0.0080	13888.6249	62.4312
59	-9393.6000	12.3403	15481.1146	-9598.7000	15485.8473	-4.7327	0.0158	15420.1165	60.9982
60	-10358.3000	14.5759	17029.1764	-10558.2222	17023.2207	5.9557	0.0199	16952.6018	76.5746
61	-11318.5000	11.2769	18575.8748	-11523.5000	18568.9868	6.8880	0.0230	18502.1186	73.7562
62	-12252.8000	14.8389	20074.1591	-12457.2000	20063.3941	10.7650	0.0359	20003.4881	70.6710
63	-12124.6000	0.9248	19881.9972	-12342.8000	19880.3362	1.6610	0.0055	19819.5353	62.4619
64	-11182.8000	11.9485	18357.0715	-11391.4000	18357.4950	-0.4236	0.0014	18289.7047	67.3668
65	-10249.1000	11.7165	16856.5487	-10459.3000	16864.7627	-8.2141	0.0274	16794.6098	61.9389
66	-9233.6000	17.9628	15298.7194	-9490.1000	15311.7936	-13.0742	0.0436	15246.6677	52.0517
67	-8291.5000	11.7977	13710.5546	-8499.0000	13722.8668	-12.3122	0.0410	13663.7485	46.8061
68	-7314.6000	8.7645	12144.0060	-7521.0000	12154.0826	-10.0766	0.0336	12101.7516	42.2544
69	-6326.6000	7.3069	10560.0621	-6533.1000	10568.5516	-8.4895	0.0283	10522.4924	37.5697
70	-5334.2222	1.9788	8965.6824	-5545.1000	8981.9891	-16.3067	0.0544	8942.3494	23.3330
Column 1	2	3	4	5	6	7	8	9	10

Figure A1.

ENGINE TEST FACILITY	TEST DATE: 3- 3-75 726 HRS	TEST: CG13 DATA POINT: 5302
TEST CELL: J-2	COMP DATE: 3-12-75 1032 HRS	PROGRAM REVISION NO. I
TEST ARTICLE:	COMP RUN: OFF LINE	INSTRUMENT BOOK REVISION NO. 09
TEST ARTICLE S/N:	PROGRAM: THRUST CALIBRATION	FLIGHT NOZZLE TEST

***** R-CAL 5401

LOAD	TARE	LOAD	TARE	LOAD	TARE	CXX	RNO
.50000+04	.24318+02	.10000+05	.44936+02	.20000+05	.68918+02	-.69238+02	-.16874+01

POSITIVE THRUST COEFFICIENTS			POSITIVE TARE COEFFICIENTS		
A	B	C	A	B	C
.613235+02	-.161122+01	-.446176-06	-.205184+01	.584913-02	-.115032-06

REC. NO.	CH.NO.72 FACT-1 COUNTS	FACT-1 DEVIATION FROM AVG.	FACT AVG.APP. R-CAL LD	CH.NO.68 FA-1 COUNTS	FA-1 CALC.LOAD	ERROR	PERCENT ERROR	FA-1 R-CAL LD	FACT,FA-1 R-CAL LD DELTA
71	-4361.5000	2.0642	7401.0422	-4562.9000	7403.8769	-2.8347	0.0094	7371.4825	29.5597
72	-3421.6000	2.4420	5888.9019	-3626.1111	5897.9253	-9.0234	0.0301	5873.2433	15.6586
73	-2512.7000	2.2191	4424.8408	-2708.5000	4422.0440	2.7969	0.0093	4402.9559	21.8849
74	-1688.3000	3.1471	3095.5961	-1855.4000	3097.5346	-1.9385	0.0065	3083.9635	11.6327
75	-1007.5556	4.1080	1997.7840	-1208.3000	2007.5111	-9.7272	0.0324	1998.9316	-1.1476
76	-573.0000	6.1594	1295.5237	-768.9000	1299.9280	-4.4043	0.0147	1294.8066	0.7171
77	-271.3000	2.5977	813.0005	-469.1000	817.0494	-4.0489	0.0135	814.3863	-1.3858
78	105.4444	-1.4419	210.0096	-92.8000	210.8411	-0.8314	0.0028	211.3771	-1.3675
79	218.0000	1.7926	25.4197	19.6000	29.7434	-4.3237	0.0144	31.2596	-5.8399
80	220.2222	-1.0412	24.6729	17.8889	32.5004	-7.8276	0.0261	34.0016	-9.3287
81	219.1111	7.3982	18.0237	22.6667	24.8023	-6.7785	0.0226	26.3454	-8.3216
84	224.3000	5.4823	11.5791	26.4000	18.7870	-7.2079	0.0240	20.3628	-8.7837
85	229.0000	3.2819	6.2066	33.1111	7.9737	-1.7671	0.0059	9.6085	-3.4019
86	231.3000	3.3072	2.4754	33.7000	7.0249	-4.5495	0.0152	8.6648	-6.1894
87	233.3333	6.1769	-3.6705	36.1000	3.1579	-6.8283	0.0228	4.8189	-8.4893
90	239.7000	2.4564	-10.2083	41.3333	-5.2744	-4.9339	0.0164	-3.5602	-6.6481
91	243.4000	0.7904	-14.5039	35.3000	4.4469	-18.9508	0.0632	6.1008	-20.6047
92	240.3000	3.5487	-12.2673	37.2000	1.3855	-13.6528	0.0455	3.0561	-15.3235
93	235.5556	2.1536	-3.2277	40.8889	-4.5583	1.3305	0.0044	-2.8495	-0.3783
94	246.3333	-4.4988	-17.1636	38.2000	-0.2258	-16.9378	0.0565	1.4537	-18.6172
95	237.3000	4.4003	-8.2853	37.0000	1.7077	-9.9930	0.0333	3.3766	-11.6619
96	234.9000	4.7269	-4.7448	36.6000	2.3522	-7.0970	0.0237	4.0176	-8.7624
97	237.2222	2.0630	-5.8226	36.0000	3.3190	-9.1416	0.0305	4.9791	-10.8017
98	239.1111	0.3952	-7.1983	39.3000	-1.9982	-5.2001	0.0173	-0.3084	-6.8896
99	237.7778	-1.1602	-3.4946	37.5000	0.9021	-4.3967	0.0147	2.5754	-6.0700
100	234.4444	7.0661	-6.3500	35.9000	3.4801	-9.8301	0.0328	5.1393	-11.4893

Figure A2.

ENGINE TEST FACILITY	TEST DATE: 3- 3-75 726 HRS	TEST: CG13 DATA POINT: 5302
TEST CELL: J-2	COMP DATE: 3-12-75 1032 HRS	PROGRAM REVISION NO. I
TEST ARTICLE:	COMP RUN: OFF LINE	INSTRUMENT BOOK REVISION NO. 09
TEST ARTICLE S/N:	PROGRAM: THRUST CALIBRATION	FLIGHT NOZZLE TEST

***** R-CAL 5401

LOAD	TARE	LOAD	TARE	LOAD	TARE	CXX	RNO
.50000+04	.29478+02	.10000+05	.53636+02	.20000+05	.84686+02	-.91727+02	-.21774+00

POSITIVE THRUST COEFFICIENTS A	B	C	POSITIVE TARE COEFFICIENTS A	B	C
.128418+03	-.193952+01	-.860438-06	-.435797+00	.655821-02	-.115105-06

REC. NO.	CH.NO.73 FACT-2 COUNTS	FACT-2 DEVIATION FROM AVG.	FACT AVG.APP. R-CAL LD	CH.NO.69 FA-2 COUNTS	FA-2 CALC.LOAD	ERROR	PERCENT ERROR	FA-2 R-CAL LD	FACT,FA-1 R-CAL LD DELTA
36	128.6667	-0.9009	4.0761	67.6667	-2.8270	6.9031	0.0230	-2.5864	6.6624
37	131.8000	-4.6491	1.9391	65.0000	2.3453	-0.4062	0.0014	2.5462	-0.6071
38	128.7000	-0.6816	3.7941	72.8000	-12.7838	16.5780	0.0553	-12.4559	16.2500
39	128.6889	-2.8820	5.6397	68.8000	-5.0253	10.6650	0.0355	-4.7654	10.4051
40	126.9000	-6.2761	9.0129	66.4000	-0.3701	9.3831	0.0313	-0.1511	9.1640
41	125.7000	-5.9294	14.6767	59.0000	13.9831	0.6936	0.0023	14.1074	0.5693
42	119.8000	-2.4832	22.3121	60.5556	10.9659	11.3462	0.0378	11.1101	11.2021
43	116.0000	-2.0013	25.2110	55.6000	20.5778	4.6332	0.0154	20.6588	4.5522
44	112.1000	-2.5832	36.8746	54.1000	23.4872	13.3873	0.0446	23.5491	13.3255
46	107.7000	-1.8168	44.3724	46.3000	38.6162	5.7563	0.0192	38.5787	5.7938
47	102.6667	-0.0886	52.0981	44.3000	42.4954	9.6027	0.0320	42.4324	9.6657
48	-29.5000	-10.3464	310.5972	-85.3000	293.8528	16.7444	0.0558	292.1546	18.4426
49	-579.9000	-4.2206	1338.2572	-611.2222	1313.5751	24.6821	0.0823	1305.5379	32.7193
50	-1172.2000	-6.5193	2453.0400	-1194.8000	2444.5299	8.5101	0.0284	2430.0159	23.0242
51	-1804.4000	-7.2779	3641.2248	-1806.1111	3628.6025	12.6222	0.0421	3607.9323	33.2924
52	-2452.5000	-1.6441	4852.8812	-2427.7000	4831.9232	20.9580	0.0699	4805.6527	47.2285
53	-3207.7000	-1.3971	6269.2144	-3164.2000	6256.8371	12.3773	0.0413	6223.7241	45.4903
54	-4024.8000	-5.0546	7801.8569	-3956.3000	7788.2791	13.5777	0.0453	7746.2159	55.6410
55	-4840.1000	-9.3775	9331.7966	-4751.5000	9324.6286	7.1680	0.0239	9274.6662	57.1304
56	-5656.3333	-5.8842	10855.6665	-5546.0000	10858.5389	-2.8724	0.0096	10801.7710	53.8955
57	-6490.7000	-6.7894	12416.1222	-6351.3000	12412.1919	3.9303	0.0131	12348.4525	67.6696
58	-7309.9000	-12.1893	13951.0561	-7146.2000	13944.6858	6.3703	0.0212	13874.0098	77.0463
59	-8129.3000	-12.3403	15481.1146	-7943.7000	15481.0995	0.0151	0.0001	15404.5569	76.5577
60	-8957.1111	-14.5759	17029.1764	-8750.2000	17033.7390	-4.5626	0.0152	16952.3767	76.7997
61	-9783.4000	-11.2769	18575.8748	-9548.0000	18568.5284	7.3464	0.0245	18487.1546	88.7202
62	-10580.2222	-14.8389	20074.1591	-10325.0000	20062.2504	11.9087	0.0397	19983.1774	90.9817
63	-10485.2000	-0.9248	19881.9972	-10230.6000	19880.8292	1.1681	0.0039	19801.4212	80.5760
64	-9666.4000	-11.9485	18357.0715	-9440.1000	18361.0169	-3.9454	0.0132	18279.4058	77.6657
65	-8866.3000	-11.7165	16856.5487	-8661.5000	16863.0324	-6.4837	0.0216	16782.1453	74.4033
66	-8028.6000	-17.9628	15298.7194	-7851.5000	15303.5287	-4.8093	0.0160	15227.6084	71.1110
67	-7181.3000	-11.7977	13710.5546	-7031.3000	13723.2364	-12.6818	0.0423	13653.4959	57.0587
68	-6343.9000	-8.7645	12144.0060	-6212.1000	12143.7152	0.2908	0.0010	12081.3025	62.7035
69	-5497.6000	-7.3069	10550.0621	-5399.4000	10575.5857	-15.5236	0.0517	10519.9918	40.0703
70	-4648.4000	-1.9789	8965.6824	-4573.8000	8981.4015	-15.7191	0.0524	8933.1098	32.5726

Figure A3.

ENGINE TEST FACILITY	TEST DATE: 3- 3-75 726 HRS	TEST: CG13	DATA POINT: 5302
TEST CELL: J-2	COMP DATE: 3-12-75 1032 HRS	PROGRAM REVISION NO. I	
TEST ARTICLE:	COMP RUN: OFF LINE	INSTRUMENT BOOK REVISION NO. 09	
TEST ARTICLE S/N:	PROGRAM: THRUST CALIBRATION	FLIGHT NOZZLE TEST	

***** R-CAL 5401

LOAD	TARE	LOAD	TARE	LOAD	TARE	CXX	RNO
.50000+04	.29478+02	.10000+05	.53636+02	.20000+05	.84686+02	-.91727+02	-.21774+00

POSITIVE THRUST COEFFICIENTS A	B	C	POSITIVE TARE COEFFICIENTS A	B	C
.128418+03	-.193952+01	-.860438-06	-.435797+00	.655821-02	-.115105-06

REC. NO.	CH.NO.73 FACT-2 COUNTS	FACT-2 DEVIATION FROM AVG.	FACT AVG.APP. R-CAL LD	CH.NO.69 FA-2 COUNTS	FA-2 CALC.LOAD	ERROR	PERCENT ERROR	FA-2 R-CAL LD	FACT,FA-1 R-CAL LD DELTA
71	-3812.2000	-2.0642	7401.0422	-3761.5000	7411.7539	-10.7117	0.0357	7371.7917	29.2505
72	-3003.9000	-2.4420	5888.9019	-2982.0000	5904.4198	-15.5180	0.0517	5873.5183	15.3836
73	-2224.3000	-2.2191	4424.8408	-2213.3000	4416.9459	7.8949	0.0263	4392.5320	32.3088
74	-1516.1000	-3.1471	3095.5961	-1532.7000	3099.1012	-3.5051	0.0117	3081.1049	14.4912
75	-931.1000	-4.1080	1997.7840	-965.4000	2000.0301	-2.2461	0.0075	1987.9921	9.7919
76	-556.1000	-6.1894	1295.5237	-601.5000	1294.7288	0.7949	0.0026	1286.8044	8.7193
77	-301.1111	-2.5977	813.0005	-354.3000	815.4824	-2.4818	0.0083	810.4824	2.5181
78	17.7778	1.4419	210.0096	-39.0000	204.0579	5.9517	0.0198	202.9406	7.0690
79	117.7778	-1.7926	25.4197	48.5000	34.3491	-8.9294	0.0298	34.3396	-8.9199
80	116.6667	1.0412	24.6729	53.1000	25.4269	-0.7540	0.0025	25.4760	-0.8031
81	124.7000	-7.3982	18.0237	52.7778	26.0518	-8.0281	0.0268	26.0968	-8.0731
84	127.1111	-5.4823	11.5791	55.7000	20.3839	-8.8048	0.0293	20.4661	-8.8870
85	128.8000	-3.2819	6.2066	66.3333	-0.2408	6.4474	0.0215	-0.0229	6.2295
86	130.8000	-3.3072	2.4754	62.7000	6.8065	-4.3311	0.0144	6.9780	-4.5026
87	135.6000	-6.1769	-3.6705	61.0000	10.1039	-13.7744	0.0459	10.2537	-13.9242
90	137.1000	-2.4564	-10.2083	67.3000	-2.1158	-8.0925	0.0270	-1.8814	-8.3269
91	138.5000	-0.7904	-14.5039	69.1000	-5.6072	-8.8967	0.0297	-5.3421	-9.1618
92	138.7778	-3.5487	-12.2673	67.0000	-1.5339	-10.7334	0.0358	-1.3046	-10.9627
93	133.2222	-2.1536	-3.2277	66.2000	0.0178	-3.2455	0.0108	0.2340	-3.4617
94	137.1000	4.4988	-17.1636	67.0000	-1.5339	-15.6296	0.0521	-1.3046	-15.8589
95	137.1111	-4.4003	-8.2853	65.4444	1.4833	-9.7685	0.0326	1.6898	-9.9751
96	135.4000	-4.7269	-4.7448	65.4444	1.4833	-6.2281	0.0208	1.6898	-6.4346
97	134.5556	-2.0630	-5.8226	63.0000	6.2246	-12.0472	0.0402	6.4000	-12.2226
98	134.4000	-0.3952	-7.1983	60.7000	10.6858	-17.8840	0.0596	10.8318	-18.0300
99	131.6000	1.1602	-3.4946	65.3000	1.7635	-5.2580	0.0175	1.9682	-5.4527
100	137.5000	-7.0661	-6.3500	64.0000	4.2850	-10.6349	0.0354	4.4731	-10.8230

Figure A4.

ENGINE TEST FACILITY	TEST DATE: 3- 3-75 726 HRS	TEST: CG13	DATA POINT: 5302
TEST CELL: J-2	COMP DATE: 3-12-75 1032 HRS	PROGRAM REVISION NO. I	
TEST ARTICLE:	COMP RUN: OFF LINE	INSTRUMENT BOOK REVISION NO. 09	
TEST ARTICLE S/N:	PROGRAM: THRUST CALIBRATION	FLIGHT NOZZLE TEST	

***** R-CAL 5401

LOAD	TARE	LOAD	TARE	LOAD	TARE	CXX	RNO
-.30000+04	-.12118+02	-.60000+04	-.29841+02	-.10000+05	-.44495+02	.35698+02	.11342+02

NEGATIVE THRUST COEFFICIENTS A	B	C	NEGATIVE TARE COEFFICIENTS A	B	C
.744237+02	-.161307+01	.713267-06	.113751+02	.879297-02	.320596-06

REC. NO.	CH.NO.70 FACC-1 COUNTS	FACC-1 DEVIATION FROM AVG.	FACC AVG.APP. R-CAL LD	CH.NO.68 FA-1 COUNTS	FA-1 CALC.LOAD	ERROR	PERCENT ERROR	FA-1 R-CAL LD	FACC,FA-1 R-CAL LD DELTA
3	-126.8889	0.8477	4.0012	41.4000	7.6439	-3.6427	0.0364	-3.6668	7.6680
4	-128.8880	-3.1172	9.5644	44.4000	2.8048	6.7595	0.0676	-8.4646	18.0290
5	-127.2222	1.9130	3.2022	41.3333	7.7514	-4.5492	0.0455	-3.5602	6.7625
6	-128.4000	2.6426	3.4140	45.6667	0.7617	2.6522	0.0265	-10.4903	13.9042
7	-125.3333	0.9977	2.6080	48.7000	-4.1311	6.7391	0.0674	-15.3413	17.9494
8	-113.8000	-0.8093	-4.8020	50.0000	-6.2280	1.4260	0.0143	-17.4204	12.6184
9	36.3000	1.3792	-126.9449	121.1000	-120.9085	-6.0364	0.0604	-131.1268	4.1819
10	349.5000	-1.3283	-374.5351	273.8000	-367.1811	-7.3540	0.0735	-375.3317	0.7966
11	482.5000	-1.7729	-480.3792	344.1111	-480.5668	0.1876	0.0019	-487.7765	7.3973
12	1691.8000	1.8011	-1450.3809	936.6010	-1435.7511	-14.6298	0.1463	-1435.3122	-15.0687
13	3899.7778	-9.1412	-3203.9724	2025.3333	-3189.6530	-14.3194	0.1432	-3176.4650	-27.5074
14	6214.2000	1.2437	-5060.8588	3178.9000	-5046.1536	-14.7052	0.1471	-5021.3023	-39.5565
15	8383.9000	-4.4102	-6784.6752	4256.2222	-6778.2354	-6.4399	0.0644	-6744.7540	-39.9212
16	10409.3000	-3.0286	-8400.2874	5260.7000	-8391.7089	-8.5785	0.0859	-8352.0885	-48.1989
17	12317.5000	-1.6653	-9922.1863	6214.0000	-9921.6453	-0.5411	0.0054	-9877.5298	-44.6565
18	14055.8000	4.6410	-11313.6447	7074.5000	-11301.5351	-12.1096	0.1211	-11254.4755	-59.1693
19	12454.7778	-1.1973	-10032.0431	6292.0000	-10046.7689	14.7257	0.1473	-10002.3430	-29.7001
20	10429.4000	-0.3478	-8418.9848	5285.4444	-8431.4372	12.4525	0.1245	-8391.6838	-27.3010
21	8282.4000	-0.5713	-6707.6084	4214.8000	-6711.6688	4.0604	0.0406	-6678.4714	-29.1369
22	6023.6000	-12.2831	-4895.4045	3095.5000	-4911.9968	16.5923	0.1659	-4887.9252	-7.4793
23	3696.4000	1.6117	-3052.1932	1945.9000	-3061.7465	9.5533	0.0955	-3049.4316	-2.7517
24	1521.2000	-3.6660	-1308.5766	859.5000	-1311.4822	2.9056	0.0291	-1312.0103	3.4337
25	451.4444	-0.7404	-456.5932	335.4444	-466.5911	9.9979	0.1000	-473.9164	17.3232
26	205.4444	-6.9937	-253.7459	208.3333	-261.6014	7.8555	0.0786	-270.6344	16.8885
27	-17.3000	-0.8319	-81.8986	100.1111	-87.0553	5.1567	0.0516	-97.5604	15.6618
28	-117.2000	-1.3667	-1.5274	47.4444	-2.1059	0.5784	0.0058	-13.3334	11.8060
31	-122.2000	-0.1611	1.2628	46.3333	-0.3136	1.5764	0.0158	-11.5565	12.8192
32	-125.8000	0.0191	3.9596	42.0000	6.6761	-2.7165	0.0272	-4.6264	8.5860
33	-123.0000	-1.1722	2.9133	44.0000	3.4500	-0.5368	0.0054	-7.8249	10.7382
34	-118.1111	-4.5239	2.3579	40.3000	9.4182	-7.0603	0.0706	-1.9077	4.2656

Figure A5.

ENGINE TEST FACILITY	TEST DATE: 3- 3-75 726 HRS	TEST: CG13 DATA POINT: 5302
TEST CELL: J-2	COMP DATE: 3-12-75 1032 HRS	PROGRAM REVISION NO. I
TEST ARTICLE:	COMP RUN: OFF LINE	INSTRUMENT BOOK REVISION NO. 09
TEST ARTICLE S/N:	PROGRAM: THRUST CALIBRATION	FLIGHT NOZZLE TEST

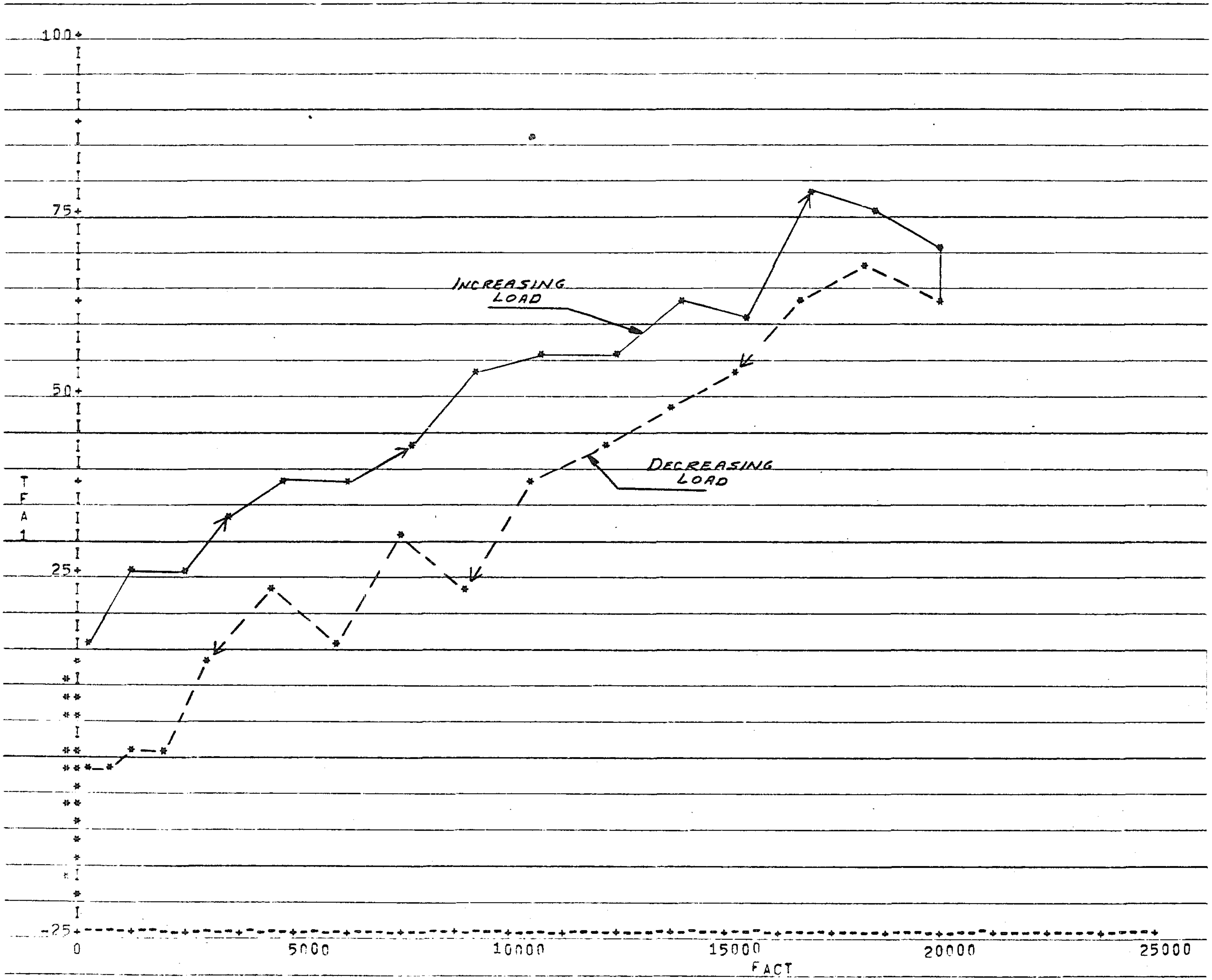
***** R-CAL 5401

LOAD	TARE	LOAD	TARE	LOAD	TARE	CXX	RNO
-.30000+04	-.12639+02	-.60000+04	-.30751+02	-.10000+05	-.46362+02	.39020+02	.10960+02

NEGATIVE THRUST COEFFICIENTS A	B	C	NEGATIVE TARE COEFFICIENTS A	B	C
.139593+03	-.193962+01	.111307-05	.109620+02	.878190-02	.304952-06

REC. NO.	CH.NO.71 FACC-2 COUNTS	FACC-2 DEVIATION FROM AVG.	FACC AVG.APP. R-CAL LD	CH.NO.69 FA-2 COUNTS	FA-2 CALC.LOAD	ERROR	PERCENT ERROR	FA-2 R-CAL LD	FACC,FA-1 R-CAL LD DELTA
3	-249.5556	-0.8477	4.0012	66.5000	10.6133	-6.6122	0.0661	-0.3433	4.3445
4	-259.7778	3.1172	9.5644	65.5556	12.4451	-2.8807	0.0288	1.4757	8.0886
5	-247.5556	-1.9130	3.2022	75.0000	-5.8721	9.0744	0.0907	-16.6856	19.8879
6	-247.0000	-2.6426	3.4140	73.7000	-3.3508	6.7648	0.0676	-14.1862	17.6002
7	-247.9000	-0.9977	2.6080	80.5556	-16.6469	19.2549	0.1925	-27.3669	29.9749
8	-241.8869	0.8093	-4.8020	72.4000	-0.8295	-3.9724	0.0397	-11.6868	6.8848
9	-108.5000	-1.3792	-126.9449	132.1000	-116.6115	-10.3333	0.1033	-126.4675	-0.4774
10	154.2222	1.3283	-374.5351	262.2000	-368.8995	-5.6356	0.0564	-376.6010	2.0659
11	267.3000	1.7729	-480.3792	317.4000	-475.9312	-4.4480	0.0445	-482.7298	2.3507
12	1311.8000	-1.8011	-1450.3809	814.4000	-1439.2984	-11.0825	0.1108	-1438.2743	-12.1066
13	3181.4000	9.1412	-3203.9724	1717.8000	-3189.0087	-14.9637	0.1496	-3175.1733	-28.7991
14	5188.6000	-1.2437	-5060.8588	2680.9000	-5052.3454	-8.5134	0.0851	-5026.8531	-34.0057
15	7037.5000	4.4102	-6784.6752	3573.5556	-6777.5474	-7.1278	0.0713	-6743.1452	-41.5300
16	8776.3333	3.0286	-8400.2874	4409.9000	-8392.3095	-7.9779	0.0798	-8351.2074	-49.0799
17	10412.7778	1.6653	-9922.1863	5200.7000	-9917.7050	-4.4814	0.0448	-9871.7002	-50.4862
18	11914.4000	-4.6410	-11313.6447	5920.8000	-11305.5142	-8.1305	0.0813	-11256.2560	-57.3887
19	10531.3000	1.1973	-10032.0431	5263.7778	-10039.3174	7.2743	0.0727	-9992.9815	-39.0616
20	8799.3000	0.3479	-8418.9848	4432.2000	-8435.3437	16.3589	0.1636	-8394.0843	-24.9005
21	6958.7000	0.5713	-6707.6084	3543.5000	-6719.4890	11.8807	0.1188	-6685.3566	-22.2518
22	4996.0000	12.2831	-4895.4045	2606.5556	-4908.5827	13.1782	0.1318	-4883.9166	-11.4879
23	3030.1000	-1.6117	-3052.1932	1648.0000	-3053.8844	1.6912	0.0169	-3040.9741	-11.2191
24	1153.8000	3.6660	-1308.5766	745.9000	-1306.5531	-2.0235	0.0202	-1306.5745	-2.0021
25	242.6889	0.7404	-456.5932	309.2000	-460.0320	3.4388	0.0344	-466.9643	10.3711
26	18.5556	6.9937	-253.7459	209.0000	-265.7394	11.9935	0.1199	-274.3173	20.5714
27	-159.2000	0.8319	-81.8986	115.0000	-83.4486	1.5500	0.0155	-93.5906	11.6920
28	-246.0000	1.3667	-1.5274	74.7000	-5.2903	3.7629	0.0376	-16.1088	14.5814
31	-247.7000	0.1611	1.2628	73.3333	-2.6397	3.9025	0.0390	-13.4813	14.7440
32	-250.4000	-0.0191	3.9596	68.0000	7.7041	-3.7445	0.0374	-3.2273	7.1869
33	-250.5556	1.1722	2.9133	72.7000	-1.4114	4.3247	0.0432	-12.2636	15.1769
34	-253.5556	4.5239	2.3579	64.3000	14.8802	-12.5223	0.1252	3.8950	-1.5371

Figure A6.



100
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-25
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DECREASING LOAD

Figure A7.

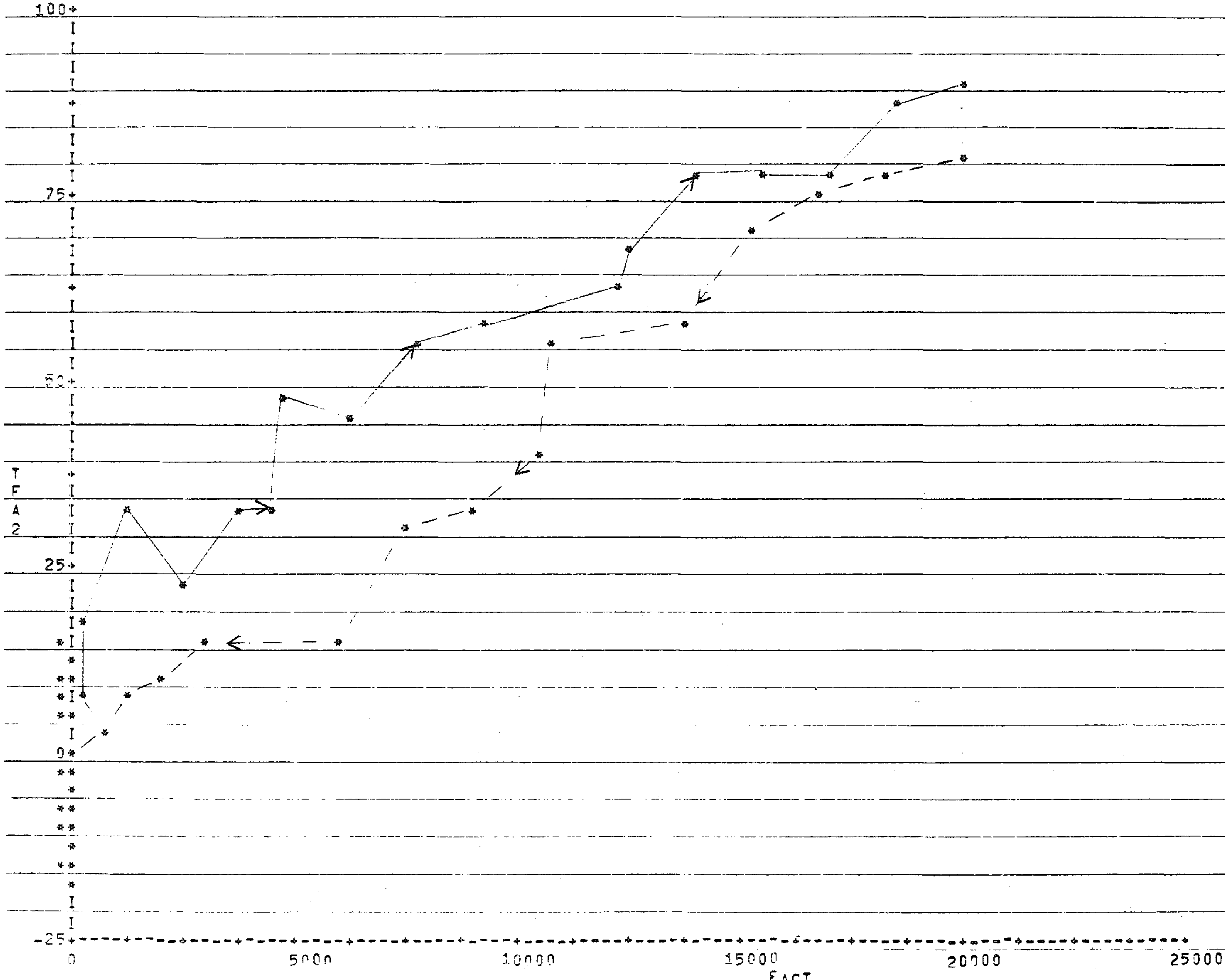

Figure A8.

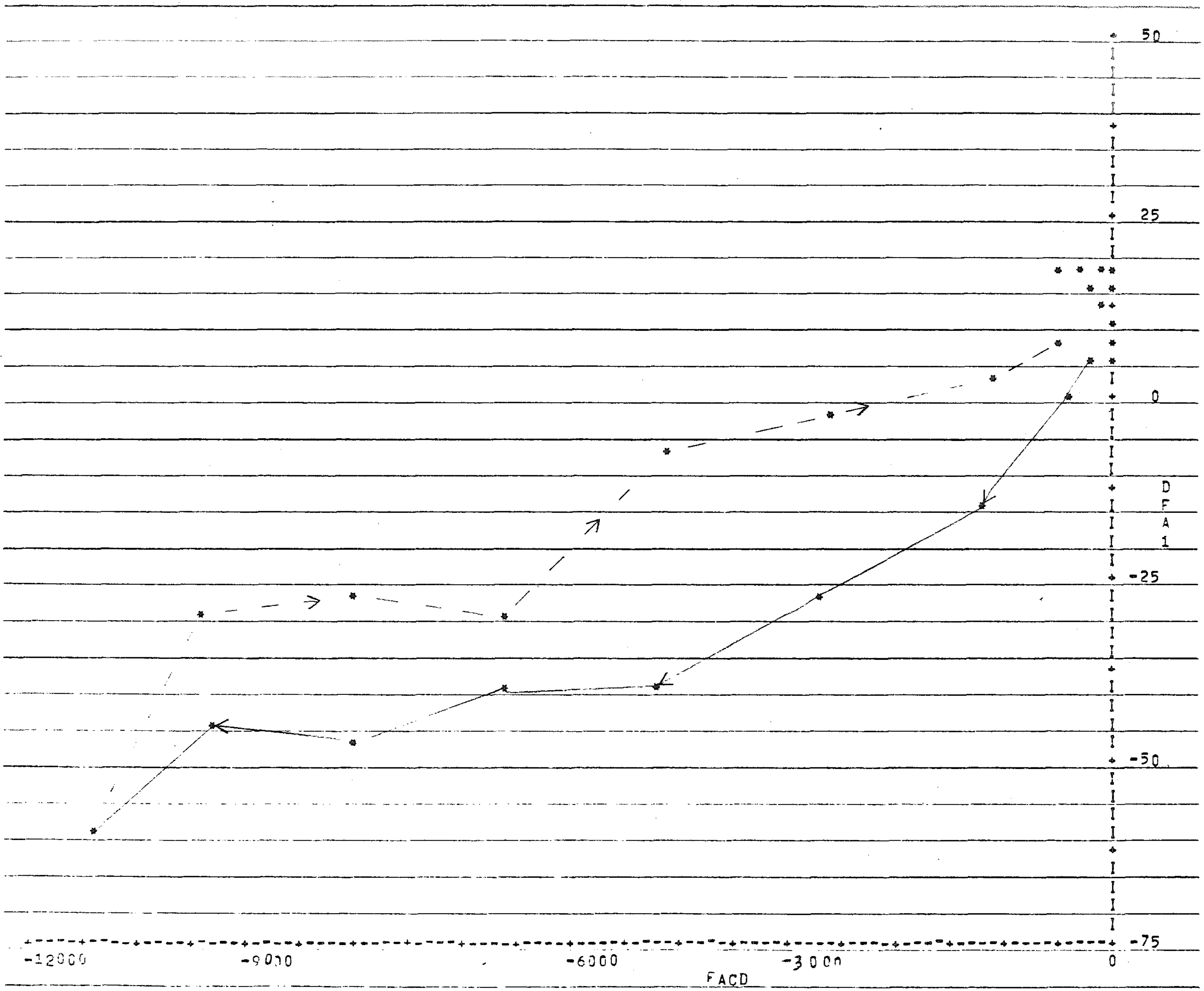

Figure A9.

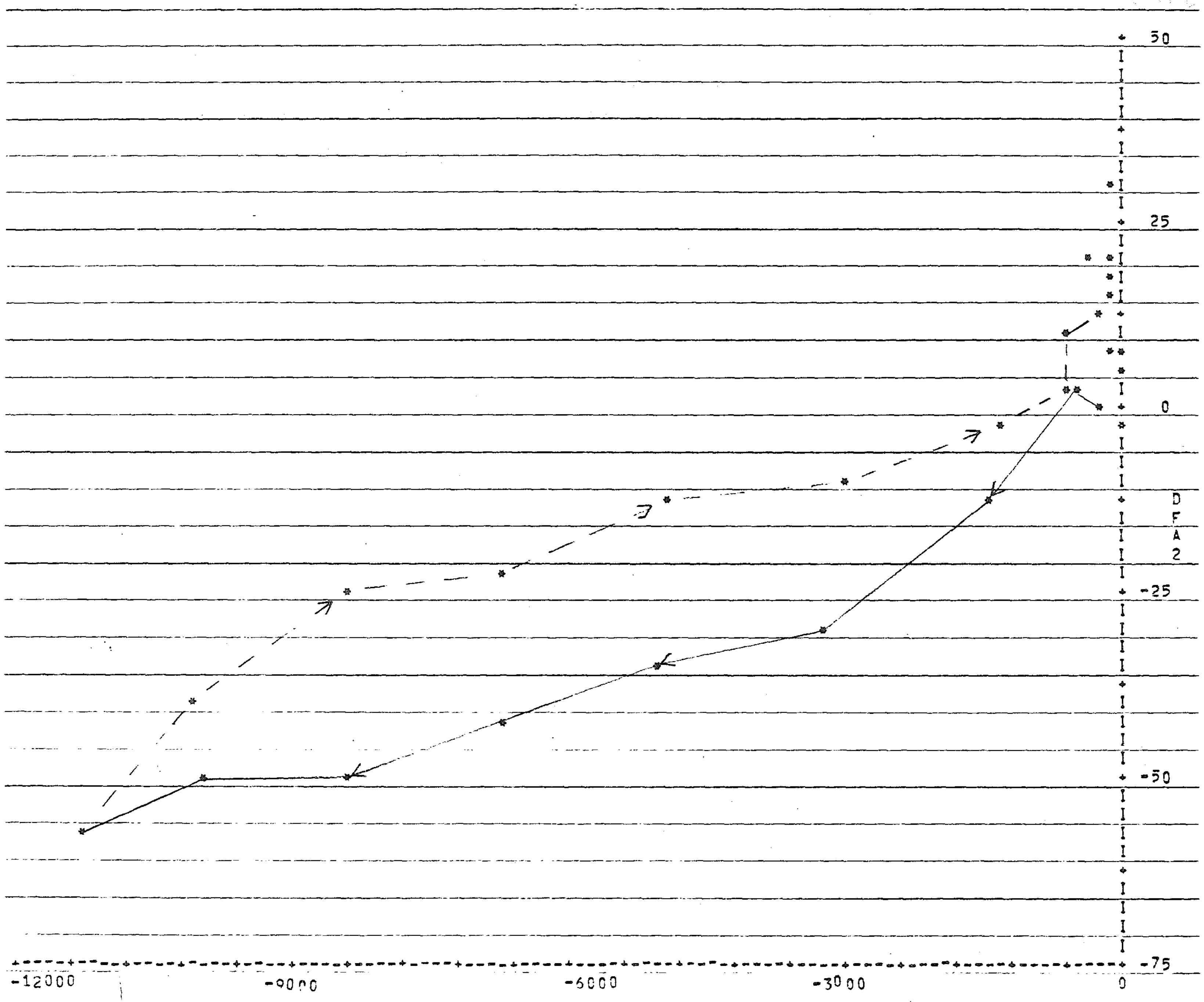

Figure A10.